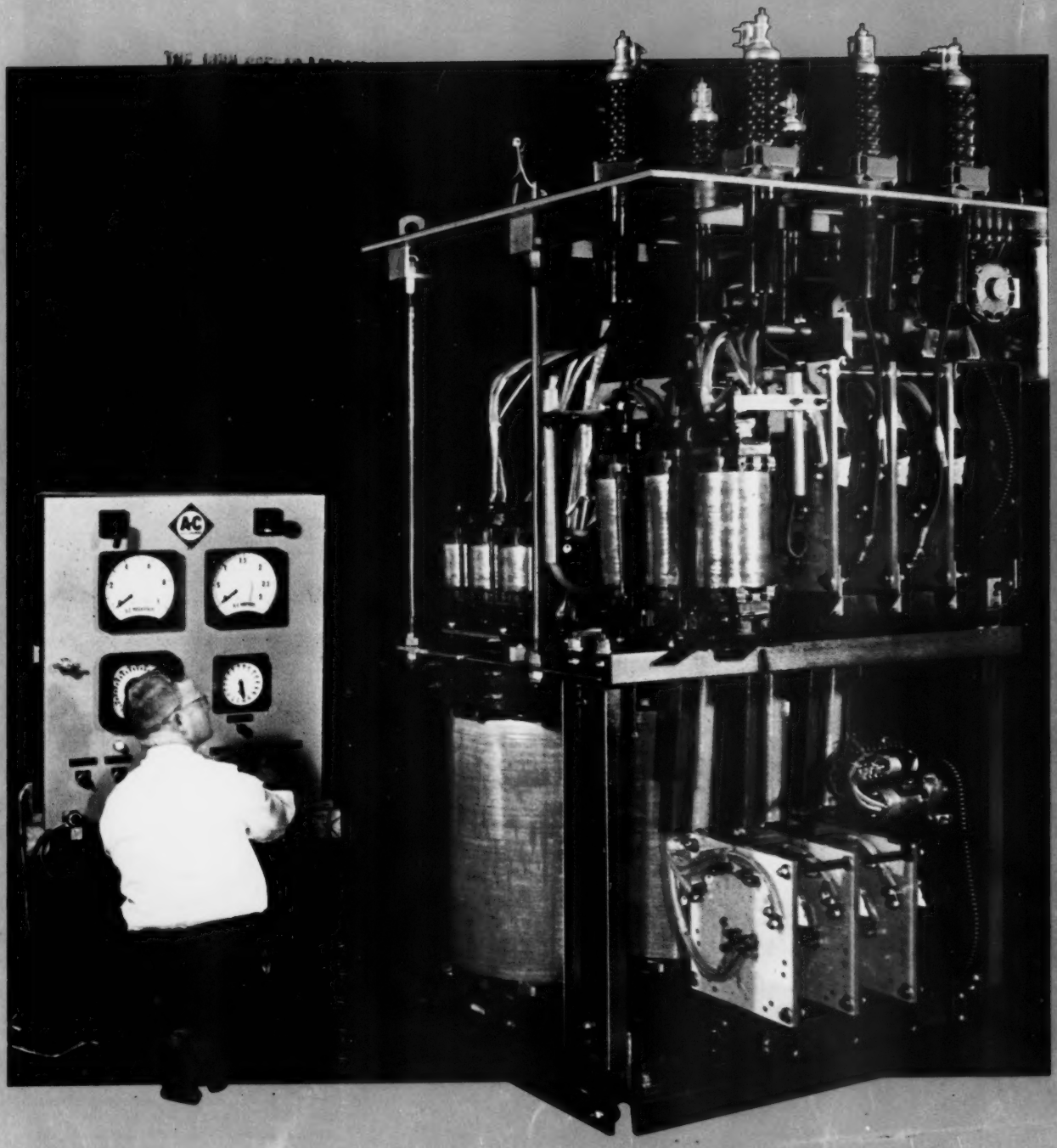
L621.3051
A438
X-1

ALLIS-CHALMERS Electrical REVIEW

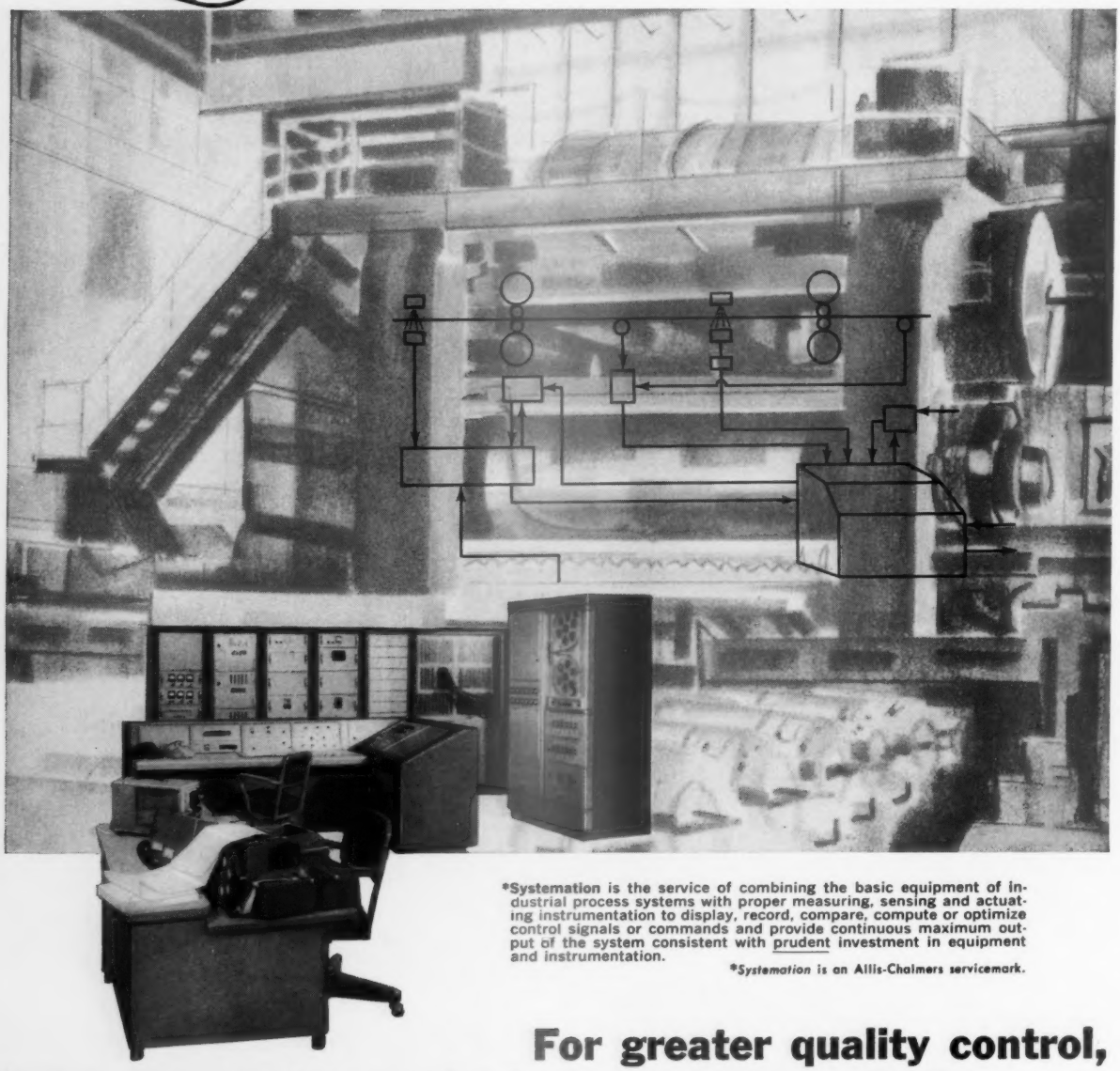
3RD QUARTER 1960



ALLIS-CHALMERS

Systemation*

A-1377



*Systemation is the service of combining the basic equipment of industrial process systems with proper measuring, sensing and actuating instrumentation to display, record, compare, compute or optimize control signals or commands and provide continuous maximum output of the system consistent with prudent investment in equipment and instrumentation.

**Systemation* is an Allis-Chalmers servicemark.

For greater quality control, lower processing costs, increased productivity

Is complete automation for you? The extent of automation most beneficial to you is determined when *Systemation* engineers of Allis-Chalmers make a feasibility study. High quality and economical production are their goals.

Allis-Chalmers is thoroughly qualified to fully or partially *Systemate* your processes. Long a supplier of processing equipment, motors, motor control and control systems, pumps, compressors, rectifiers, and electrical generation and distribution equipment — A-C has an intimate knowledge of your processes. With the addition of Consolidated Systems Corporation, Allis-Chalmers extends its ability in the areas of data gathering, handling and processing. CSC provides the experience acquired from more than 500 successful systems projects!

For the complete story on how you can benefit from "Systemation," call your nearby A-C representative. Or write **Allis-Chalmers,** *Industrial Equipment Division, Milwaukee 1, Wisconsin.*

ALLIS-CHALMERS

Electrical REVIEW

THE COVER

LOAD TAP-CHANGING transformer with wide range of operating voltages is now available for power supply to diode type rectifiers used in variety of industrial processes. The article "Controlling Diode Rectifier Output" on Page 13 gives details on this versatile transformer.

Allis-Chalmers Staff Photo by Harold Schrode

Allis-Chalmers

ELECTRICAL REVIEW

Vol. XXV No. 3

Executive Board

C. W. Schweers *F. W. Bush*
A. R. Tofte *J. L. Black*

Editor.....*R. W. Smeaton*
Technical Consultant.....*L. J. Linde*

Associate Editors

Boston Works.....*I. C. Fisk*
C-Stellarator.....*R. C. Dancy*
Control.....*R. W. Fugill*
Electrical Application.....*T. E. Bryan*
Heat Transfer & Water Conditioning...*J. S. Ferguson*
Motor & Generator.....*F. C. Osterland*
Norwood Works.....*W. H. Barclay*
Nuclear Power (Greendale Lab.).....*Gunnar Johnson*
Nuclear Power (Washington, D.C.)...*R. A. Hoover*
Office of Dir. of Engin....*Robert Mudd*
Patent.....*H. L. Swenson*
Pittsburgh Works.....*F. J. McGaughey*
Plant Engineering.....*H. Mickowski*
Rectifier.....*A. E. Brown*
Regulator.....*Frank Ladd*
Research.....*R. F. Anderson*
Steam Turbine (Turbine).....*M. C. Maloney*
Steam Turbine (Generator).....*J. A. Zimmerman*
Switchgear.....*J. A. Keymar*
Terre Haute.....*B. A. Storaasli*
Transformer.....*L. W. Schoenig*

Art Editor.....*S. M. Loch*
Production.....*J. E. Steffek*
Circulation.....*John Gumtz*

Issued quarterly. Subscription rates: U. S., Mexico, and Canada, $2.00 per year; other countries, $3.00; single copies, $1.00 in advance.

CONTENTS

Extensometer Eases Strip Hardening Control..... 4
R. C. Lopez

Watch Metering Transformer Accuracy..... 8
G. Gallousis

Housing Switchgear Against Weather..... 11
A. Ewy

Controlling Diode Rectifier Output..... 13
F. H. Ladd

Wk^2 vs Rotor Loss..... 14
R. C. Moore

Vacuum Switch for Controlling Reactive Power.... 20
R. C. Odell, H. M. Pflanz and G. N. Lester

Improve Performance with Cooperative Planning... 24
W. C. Frazier

CT's Oversaturated ?..... 28
A. H. Knable

Regulators and Transformers Combined for Substation 30
T. J. Sillers

Overloading Transformers..... 32
W. C. Sealey

Research in Ultra Purity..... 36
P. G. Grimes

Indexed regularly by Engineering Index, Inc.
Allis-Chalmers ELECTRICAL REVIEW is available to public and institutional libraries on microfilm from University Microfilms, 313 N. First St., Ann Arbor, Mich.

Address Allis-Chalmers Electrical Review, Milwaukee 1, Wisconsin

Printed in U. S. A. Copyright 1960 by Allis-Chalmers Mfg. Co.

EXTENSOMETER EASES STRIP HARDENING CONTROL

OPERATOR'S CONTROL CABINET for high speed two-stand tin temper mill, entry side of mill, has readout device for giving digital measurement of strip elongation at any instant and any speed.

by RENE C. LOPEZ
Control Department
Allis-Chalmers Mfg. Co.

Simple digital instrumentation employing all-static system assures extreme quality control of temper mill products.

IN THE PRODUCTION of sheet and tin plate products, surface hardening is checked by means of Rockwell hardness tests. This method is a spot check and requires either running the mill at relatively low speeds or stopping the mill to obtain samples. For obvious reasons this may not provide a good indication of strip hardness should mill conditions be variable with speed.

Inasmuch as surface hardness is related to elongation when the strip is cold rolled in a reduction or temper pass mill, this extension of the strip can be used as another criterion for evaluating the quality of the final product. Measuring the elongation lends itself to continuous application and thus is highly recommended for quality control of temper mill products. Because measurement is easily accomplished at low and high speeds, it is well suited for mills where the speed varies over a wide range, from 200 fpm up to 7000 or 8000 fpm.

Use of simple digital instrumentation, consisting basically of high reliability solid state devices, makes the measuring of elongation a highly reliable and accurate technique. As a result, shutdowns or difficult maintenance programs can be reduced to a minimum.

Digital techniques offer other advantages. Systems can be built with inherently high accuracy and with sufficient flexibility to allow for rapid adaptation to constantly changing parameters. When applied to measuring elongation on temper mills, this means capability of measuring exceedingly small elongation (in the order of 0.5 percent or less, i.e. 0.062″ in a 12.500″ long sample of strip) and rapid compensation for changes of mill components such as roll diameters, gear ratios, etc.

The system can be built compactly, requiring a minimum of mounting space, because of the nature of the components used with digital equipment. This is true of the computing elements and the readout components used in displaying the results of the measurement.

Elongation measured by all static system

The digital extensometer is an all static system that measures the amount of elongation of cold rolled strip as it passes through the work rolls of a reduction mill. It further computes and displays continuously the amount of elongation in percent in any one of the following methods: (1) Analog indication (deflection instrument); (2) Digital indication (numerical display); (3) Continuous record (strip chart); (4) Numerical storage (tape printer).

Measurement of elongation is accomplished with two heavy duty magnetic type pulse generators geared to con-

tact rolls, located at the entry and exit side of the mill as indicated in Figure 1. These pulse generators transmit electrical impulses at a rate proportional to the speed of rotation of the contact rolls. Under normal operation, the exit roll rotates faster than the entry roll due to reduction in strip thickness.

In the assumption that the peripherial speeds of the entry and exit rolls are identical with strip speed, computation of tension is accomplished by counting the number of pulses produced by the exit roll pulse generator during the time required to accumulate a pre-determined number of pulses produced by the entry pulse generator. This pre-determined number of pulses is a function of the entry and exit roll diameters and it can be easily obtained as shown in the Derivation of Pulse Function.

Equation (11) can be solved directly using a pair of digital counters. Assume that one of these counters is of the preset type and is used to accumulate the pulses from the entry side generator up to a preset value of $C_1 = 1000$ and that the delivery counter accumulates the pulses from the delivery side pulse generator. When coincidence is reached in the entry counter, an "off" signal is produced that stops the count in the delivery counter. Then for a count of C_1 in the entry counter the delivery counter will have accumulated over the same time a count of $C_2 = 1000\ (1 + E)$. If the elongation has been 1 percent then $C_2 = 1000\ (1 + 0.01) = 1010$ in which 10 pulses in excess of 1000 are equivalent to a 1 percent elongation. Due to unavoidable phase shifts in the system the delivery counter can differ by ± 1 from the actual count. It follows then, that the measured extension is accurate to $\pm$ 10 percent.

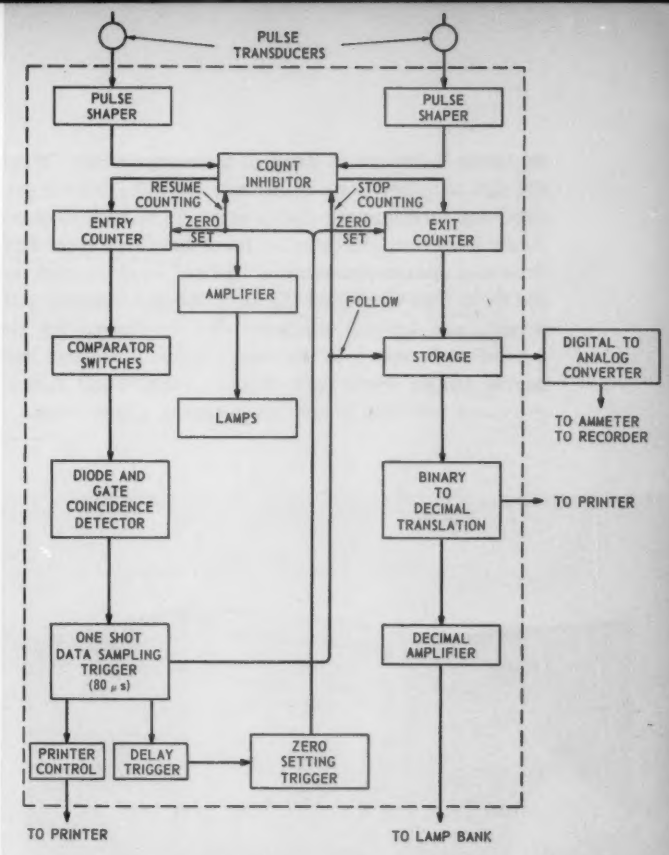
To obtain even greater accuracy, the count C_1 could be set to 10,000 so that 10,100 or 100 pulses in excess of C_1 from the delivery generator, would represent an extension of 1 percent. The accuracy of the measurement would then be 1.0 percent.

The value of strip elongation can be directly obtained by reading the last two or three least significant digits of the delivery side counter. The reading can thereafter be presented after proper conversion into any of the forms listed previously.

System components described

A general arrangement of the components making up the extensometer system is shown in Figure 1. Two pulse generators, connected to the entry and exit rolls through step-up gearing, emit pulses at a rate proportional to the rpm of the input shaft. One hundred and eighty electrical impulses per revolution of the input shaft have been selected. Their outputs are connected by co-axial cable to the pulse counters.

Two five digit counters, a preset and a display are connected to the entry and delivery pulse generators. Five comparator switches are used to store the precalculated count C_1, and also establish the level for a coincidence detector to activate a one shot data sampling trigger when



PULSE GENERATOR SIGNALS of delivery side of mill are counted and compared to entry side signals to provide control, continuous record, analog and digital indication and numerical storage. **(FIG. 1)**

MODERN STATIC CONTROL using such devices as printed circuits for system logic are now an important part of steel mill automation.

the count C_1 has accumulated in the entry counter. When the data sampling pulse is initiated a count inhibitor prevents any further accumulation of pulses in both counters. At the same time, the count inhibitor switches a three digit transistor storage matrix to its "follow" mode to read out the three least significant digits of the exit counter. Sufficient time (several microseconds) is allowed for the reading to be stored in the matrix before a one shot zero setting trigger resets both counters to zero and releases the count inhibitor to start accumulating a new count.

STATIC COMPONENT CABINET where pulse shapers, counters, inhibitors, amplifiers and similar equipment are mounted has convenient controls to adjust for change in mill operating conditions.

The reading in storage is subsequently translated to straight decimal reading for presentation in a three digit lamp bank or/and converted to analog form to operate a deflection type instrument or recorder. Other controls such as a printer command and printer operation can also be part of the system.

All the components making up the system use transistorized flip-flops and precision resistors in their outputs wherever conversion (binary codes to straight decimal or analog) is required. This eliminates any contact making devices and insures long periods of operation without maintenance.

An important feature of the system is that the information stored in the transistor matrix is held and displayed continuously during the time a new count is being accumulated — this eliminates constantly flipping the reading of the lamp bank consequently reducing any eye fatigue.

The decade counters used in this system utilize four conventional monostable flip-flop circuits to generate a binary code readout in the form of high or low voltages representing a decimal digit. Several of these units are cascaded (the output of one unit driving the next) to form a counter whose total count capacity is 99,999. These counters are capable of a maximum counting rate of 100,000 counts per second and can be reset instantly to zero by a pulse less than 5 microseconds wide.

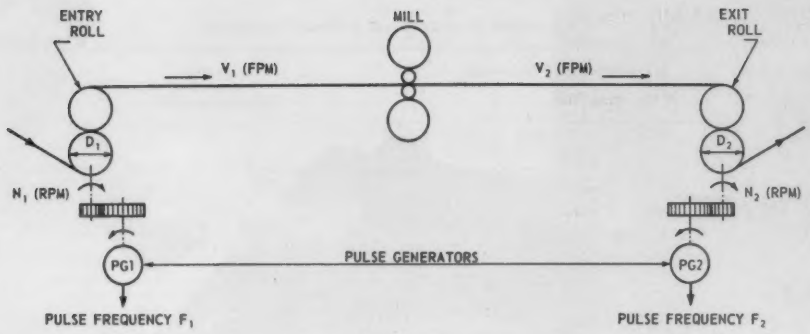
More accurate measurement is possible

Since the digital extensometer is basically simple and the amount of equipment involved is small, there are few installation problems and calibration can be easily accomplished. Numerical presentation of information is clear and devoid of reading errors.

By using higher powers of ten to set the count in the entry counter, the percent elongation can be read to greater accuracy, although greater amounts of strip length may be required to accumulate the count. This in no way detracts from system performance since higher counting rates (greater number of pulses for revolution) can easily be provided by increasing the number of pulses generated per foot of strip.

With greater system resolution (incremental strip length per pulse) the frequency of the accumulated count increases and thus it becomes feasible to consider the application of the digital extensometer to closed loop type control systems. The information from the extensometer can be used as the feedback signal on a sample-data type servo system for controlling strip elongation to a desired value. The system would control, either over a limited band or the entire band, the screwdown position and tension between mill stands.

Present experiences with this type of extensometer indicate stable measurement of strip elongation. Automatic extension control can thus be an important consideration on new mill installations and can be readily incorporated as an integral part of the overall job.



ELONGATION is used as a measure of strip hardness. Speed difference between the entry and exit rolls provides this measure. **(FIG. 2)**

Derivation of Pulse Function

Let:

$x_1,\ x_2$ = Incremental length of strip passing over the entry and delivery contact rolls for every pulse produced by the pulse generators.

$C_1,\ C_2$ = Total number of pulses to be accumulated on a given time.

$L_1,\ L_2$ = Total length of strip measured during the time that counts C_1, C_2 took place.

$N_1,\ N_2$ = Rpm of entry and exit rolls.

$D_1,\ D_2$ = Diameter of entry and exit rolls.

$V_1,\ V_2$ = Incoming and outgoing strip speed.

$R_1,\ R_2$ = Gear ratio between contact roll and pulse generator.

$F_1,\ F_2$ = Pulses per revolution of pulse generators.

Then:

$$L_1 = x_1 \cdot C_1 \quad \ldots\ldots (1)$$

$$L_2 = x_2 \cdot C_2 \quad \ldots\ldots (2)$$

We can also write the following relations:

$$L_2 = L_1 + E \cdot L_1 \quad \ldots\ldots (3)$$

Where: $E = \%$ elongation of strip.

Manipulation of equations (1), (2) and (3) yields:

$$x_2 \cdot C_2 = x_1 \cdot C_1 (1 + E)$$

$$C_2 = \frac{x_1}{x_2} \cdot C_1 (1 + E) \quad \ldots\ldots (4)$$

Assume that the count to be selected on entry roll C_1 is:

$$C_1 = 10^n \cdot \frac{x_2}{x_1} \quad \ldots\ldots (5)$$

$$n = 2,\ 3 \ldots$$

The values of x_1 and x_2 can be derived from the dimensions of the entry and exit rolls as follows:

$$x_1 = \frac{\pi \cdot D_1}{R_1 \cdot F_1} \quad \ldots\ldots (6)$$

$$x_2 = \frac{\pi \cdot D_2}{R_2 \cdot F_2} \quad \ldots\ldots (7)$$

Substituting in equation (5):

$$C_1 = \frac{D_2 \cdot R_1 \cdot F_1 \cdot 10^n}{D_1 \cdot R_2 \cdot F_2} \quad \ldots\ldots (8)$$

In practice, the gear ratios R_1 and R_2 and the pulse generators at the entry and exit side of the mill are normally the same (not necessary however) which further simplifies equation (8) to:

$$C_1 = \frac{D_2 \cdot 10^n}{D_1} \quad \ldots\ldots (9)$$

The diameters of the entry and exit rolls often differ due to uneven wear or necessary grinding (cutting) needed to remove marks developed during rolling. However, in the case of the digital extensometer, this condition does not represent a maintenance problem since, as shown in equation (9) all that is required to retain system accuracy is to compute a new ratio $\frac{D_2}{D_1}$ every time the diameter of either roll changes.

Eq. (9) (the pulse count to be established at the entry side of mill) includes a factor 10^n in which the exponent n is to be selected as 2, 3, etc. Substitution of equation (9) into (4) gives:

$$C_2 = 10^n (1 + E) \quad \ldots\ldots (10)$$

Assume that at the start of a rolling operation the diameters of the entry and exit rolls are the same $\left(\frac{D_2}{D_1} = 1\right)$ and $n = 3$ therefore

$$C_2 = 1000 (1 + E) \quad \ldots\ldots (11)$$

Watch... Metering Transformer Accuracy

SAVINGS ADD UP! CT cast in thermo-setting resin costs less than high accuracy CT (foreground) but will serve better in most applications.

by GEORGE GALLOUSIS
Pittsburgh Works
Allis-Chalmers Mfg. Co.

Selecting the best metering accuracy transformer for the application can save money, space and weight.

SPECIFYING THE HIGHEST ACCURACY or the highest price instrument transformer is not always a wise choice. The best metering accuracy instrument transformer — the one that does exactly what the job under consideration requires — is the transformer to select.

Consider the transformers shown in Table I. The Type MKE costs about 56 percent more than the Type LRM, requires more than twice the installation space and weighs over 60 percent more. Determining which transformer is best for the application, requires a knowledge of metering accuracy and its application.

In a transformer manufacturer's descriptive literature, the accuracy of a particular current transformer might be given as "0.3 B2." This designation means that with a burden of 2 ohms impedance connected to the secondary terminals, this transformer will satisfy 0.3 accuracy class requirements. Burden is the load in an instrument transformer secondary circuit and includes meters, relays and lead impedance. Table II shows the burdens for standard current transformers having 5 ampere secondaries. Seven standard burden designations are given in the table. For each of these burdens a specific resistance and inductance is defined.

These burdens are also described in terms of volt-amperes loads at given power factors. Burdens for other frequencies must have the same resistance and inductance as those shown for 60 cycles. The inverse ratio of a nonstandard current to the standard 5 ampere secondary current should be used to derive the proper nonstandard burden. Assume a one ampere secondary current transformer and a standard burden of B-1. The equivalent impedance of the testing burden is equal to

$$\frac{(5\ \text{Amp})^2}{(1\ \text{Amp})^2} \times 1\ \text{ohm or } 25\ \text{ohms.}$$

Of the four accuracy classifications shown in Table III, the three most used are 1.2, 0.6 and 0.3. Accuracy

TABLE I

Comparison of Three Types of Current Transformers

		LRM	LDM	MKE
Current Rating		100-5 Amp.	100-5 Amp.	100-5 Amp.
Insulation Class		5 KV	5 KV	5 KV
Full Wave Impulse Level		45 KV	45 KV	60 KV
Accuracy	B0.1	0.6	0.3	0.3
	B0.2	0.6	0.3	0.3
	B0.5	0.6	0.3	0.3
	B2.0	—	—	0.3
Relay Accuracy		10 H 25	10 H 25	10 H 100
Length		11½"	11½"	15"
Width		4¼"	4¼"	6¼"
Height		6½"	6½"	7¾"
Weight		13 lbs.	13 lbs.	21 lbs.
Relative Cost		100%	107%	156%

TABLE II

Standard Burdens for Standard 5-Ampere Secondary-Current Transformers

Designation of Burden	Standard Burden Characteristics		Standard Secondary-Burden Impedance Ohms and Power Factor and Standard Secondary Volt-Ampere Burdens					
			For 60-Cycle and 5-Ampere Secondary Current			For 25-Cycle and 5-Ampere Secondary Current		
	Resistance Ohms	Inductance Millihenrys	Impedance Ohms	Volt-Amperes*	Power Factor	Impedance Ohms	Volt-Amperes*	Power Factor
B-0.1	0.09	0.116	0.1	2.5	0.9	0.0918	2.3	0.98
B-0.2	0.18	0.232	0.2	5.0	0.9	0.1836	4.6	0.98
B-0.5	0.45	0.580	0.5	12.5	0.9	0.4590	11.5	0.98
B-1	0.5	2.3	1.0	25	0.5	0.617	15.4	0.81
B-2	1.0	4.6	2.0	50	0.5	1.234	30.8	0.81
B-4	2.0	9.2	4.0	100	0.5	2.468	61.6	0.81
B-8	4.0	18.4	8.0	200	0.5	4.936	123.2	0.81

*From A.S.A. Standard C57.13

parallelograms for each of these accuracy classifications, defined as standards, are shown in Figure 1. These parallelograms serve as screens to verify the ability of a transformer to meet the requirements of a specific class with a specific burden.

Two parallelograms are shown for each of the accuracy classes 1.2, 0.6, and 0.3. One of these acts as a screen for 10 percent rated current test points and the other as a screen for 100 percent rated current test points. The quantities tested to determine whether accuracy class requirements are met are known as ratio correction factor and phase angle.

To satisfy the requirements of a particular accuracy class, the ratio correction factor and phase angle test results for 100 percent rated current must fall within the smaller parallelogram and the ratio correction factor and phase angle test results for 10 percent rated current must fall within the larger parallelogram.

"The ratio correction factor" is equal to the True Ratio of the current transformer divided by the Marked Ratio of the transformer. "Phase angle" is a measure of the amount by which the angle between primary and secondary current vectors differs from 180 degrees. In a perfect current transformer the secondary current would be exactly 180 degrees out of phase with the primary current and the ratio of primary current to secondary current would be exactly equal to the marked ratio for all conditions of secondary burden and output. The extent of the departure from this perfect transformer is described by the magnitude of the ratio and phase angle errors.

Another term "instrument transformer correction factor" refers to the factor by which watthour meter registration or wattmeter indication must be multiplied to correct for the combined effect of ratio and phase angle error.

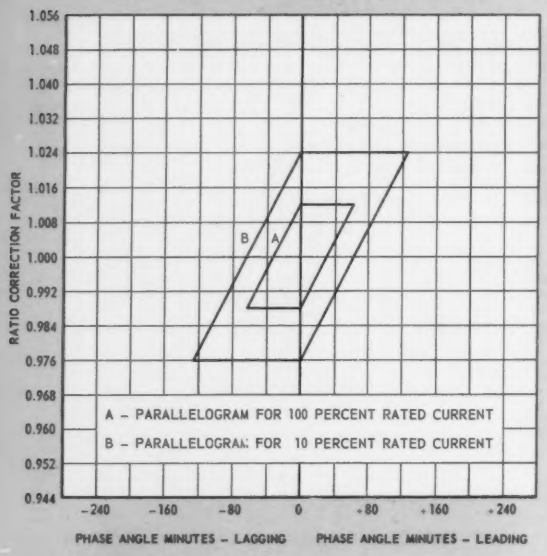
If the accuracy required by the application was 0.6 BO.5 and no other factors such as possible future changes in the installation are involved, then referring to Table I the use of an LRM rather than an LDM is indicated. If top accuracy of 0.3 BO.5 is the requirement both the LDM and the MKE will do the job, but the MKE will cost 45 percent more, weigh 62 percent more, and occupy over twice as much space. The MKE should only be used for this application if 60 kv impulse level rather than the LDM's 45 kv impulse level is an actual requirement. When the application requirement is 0.3 *B2.0* the MKE is the only one of the three transformers that is satisfactory.

TABLE III

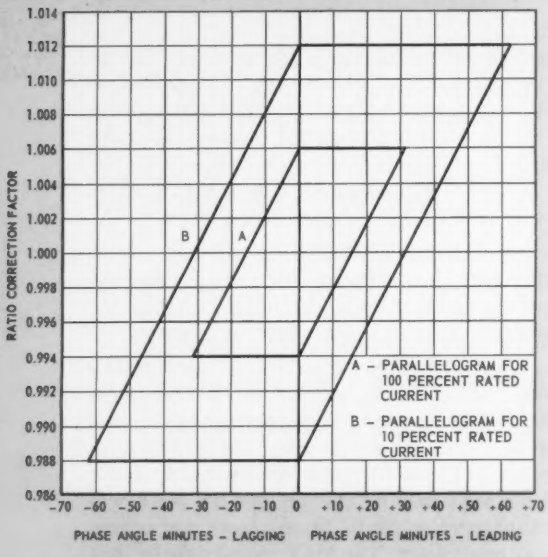
Standard Accuracy Classes and Corresponding Limits of Transformer Correction Factors for Current Transformers for Metering Service*

Accuracy Class	Limits of Transformer Correction Factor				Limits of Power Factor (Lagging) of Metered Power Load
	100-Percent Rated Current		10-Percent Rated Current		
	Minimum	Maximum	Minimum	Maximum	
1.2	0.988	1.012	0.976	1.024	0.6-1.0
0.6	0.994	1.006	0.988	1.012	0.6-1.0
0.3	0.997	1.003	0.994	1.006	0.6-1.0
0.5	0.995	1.005	0.995	1.005	0.6-1.0

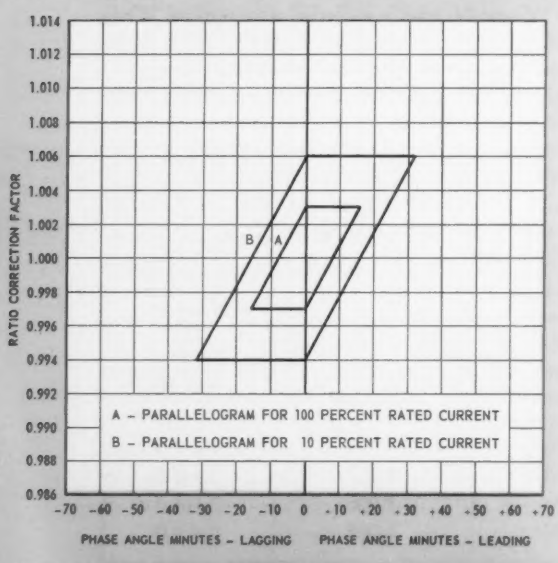
*From A.S.A. Standard C57.13



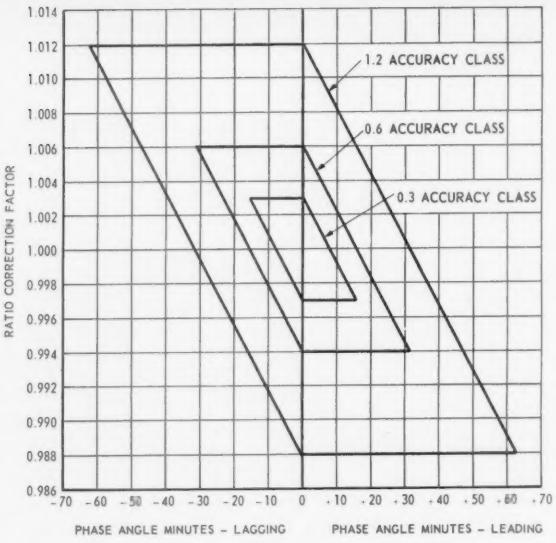
STANDARD ACCURACY LIMITS for Class 1.2 CT's. (FIGURE 1a)



STANDARD ACCURACY LIMITS for Class 0.6 CT's. (FIGURE 1b)



STANDARD ACCURACY LIMITS for Class 0.3 CT's. (FIGURE 1c)



STANDARD ACCURACY LIMITS for PT's. (FIGURE 2)

The technique for selecting a current transformer to meet relay accuracy requirements is the same as that used above. That is:

1. Determine the requirements.
2. Select the most economical device to meet these requirements.

While current transformers have been used to show the approach to instrument transformer selection, the ideas apply equally well to the selection of potential transformers. A potential transformer accuracy parallelogram is shown in Figure II and standard burdens and accuracy classes for potential transformers are given in Tables IV and V.

For either current or potential transformers we must select the best metering accuracy instrument transformer — the one that does exactly what the job under consideration requires. Selecting the best metering accuracy transformer for a specific application can save money, space, and weight.

TABLE IV

Standard Burdens for Potential Transformers

Designation of Burden	Secondary Volt-Amperes	Burden Power Factor
W	12.5	0.10
X	25	0.70
Y	75	0.85
Z	200	0.85
ZZ	400	0.85

From A.S.A. Standard C57.13

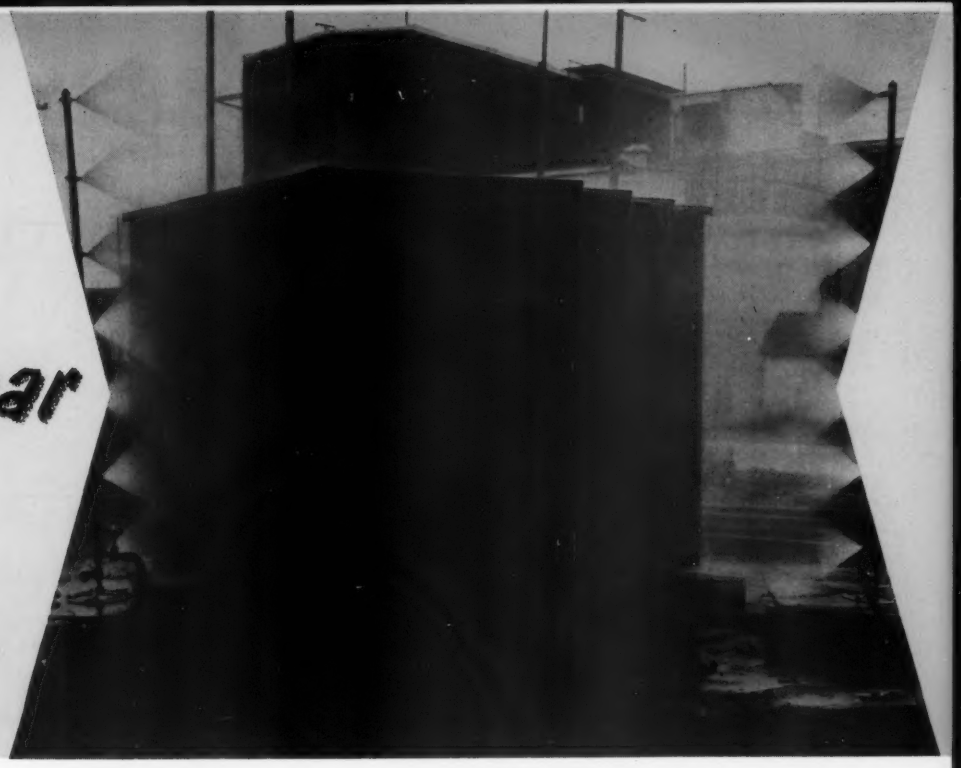
TABLE V

Standard Accuracy Classes for Potential Transformers for Metering Service

Accuracy Class	Limits of Transformer Correction Factor	Limits of Power Factor (Lagging) of Metered Power Load
1.2	1.012-0.988	0.6-1.0
0.6	1.006-0.994	0.6-1.0
0.3	1.003-0.997	0.6-1.0

From A.S.A. Standard C57.13

Housing Switchgear Against Weather



SPRAY TESTS simulating severest rain storm are used to prove weatherproof designs. Sides, roof, doors and louvers are all carefully checked for leaks that might impair operation of the substation.

by A. EWY
Chief Engineer
Switchgear Department
Allis-Chalmers Mfg. Co.

Protection against the elements is assured through stringent water tests devised for power switchgear assemblies.

SWITCHGEAR MANUFACTURERS have spent considerable time and effort in attempting to arrive at a test specification standard for testing of outdoor switchgear enclosures. Up to now, there has been confusion as to when a switchgear design can be considered weatherproof. Design tests have been few and each manufacturer has made his weatherproof design as his field experience warrants. Often, when tests were made, the type of test was very poorly improvised.

To arrive at a test standard, it is essential to derive a common definition for the term "weatherproof." According to NEMA Standards for Power Switchgear Assemblies SG-5: "Weatherproof means so constructed or protected that exposure to the weather will not interfere with its successful operation."

Weather conditions considered hazardous are rain, snow, sleet, dust, dirt, or other foreign objects. Since it would be difficult to devise a test to determine whether the equipment would operate satisfactorily under these varied conditions, it was decided to consider only a water test. If the equipment passed this test, it would withstand the normal weather hazards.

Test equals very heavy rain

A test set-up for artificial precipitation was devised. After many nozzle tests, a nozzle with a cone angle of 71 to 75 degrees was selected to provide a uniform spray over a given surface to be tested. It had a rated capacity of 5.0 gpm at 10 psi, and 7.1 gpm at 20 psi. Nozzles were placed on a stand so that the enclosure being tested received at least 0.2 inches of water per minute. This amount of water is considered by the weather bureau to be an extremely heavy rain.

The stand was placed 6 feet from the vertical surface of the equipment to be tested and the cone of the nozzle spray was directed at the equipment with the centerline of the nozzle inclined downward so the top of the spray was approximately horizontal. With a pressure of about 15 psi at the nozzles, there was little deviation of the spray from a straight line.

Water spray was directed equally to the external surfaces of the switchgear group being tested. The stand was high enough to test the roof at the same time as the side surfaces. The lowest nozzle was located so that the water spray would strike the floor about 18 inches in front of the unit.

Equipment sprayed for five minutes

Two stands were used to test a two-unit outdoor, 5-kv metal-clad switchgear group as illustrated in Figure 1. The spray was applied for a period of 5 minutes. In order to visually determine whether water had entered the housings, the inside surfaces around ventilating openings, roof joints, and door gasketing were coated with a white chalk.

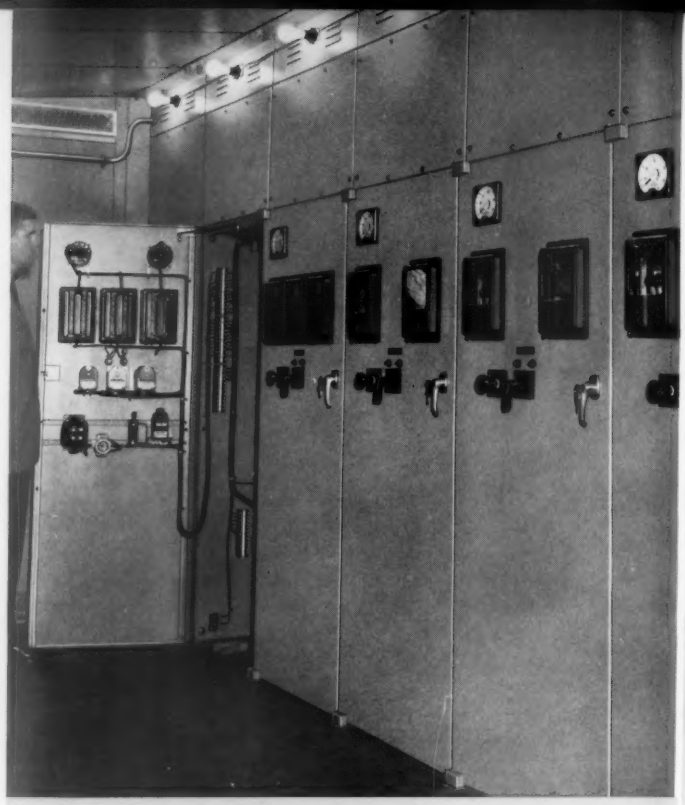
After the test, inspection of the inside of the switchgear revealed that no water entered the unit through the roof, any gasketed covers, or through the gasketed doors. Some water entered through the ventilating openings but did not get to any of the equipment in the unit. The small amount of water which did enter ran down the back of the door and did not interfere with the operation of the switchgear.

The louvered ventilating openings in the sheet steel door were backed up with filters. Removal of these filters allowed the water to enter in much larger quantities. Because this was considered a hazard to the operation of the equipment, it was necessary to retain filters in the ventilating openings to pass the test.

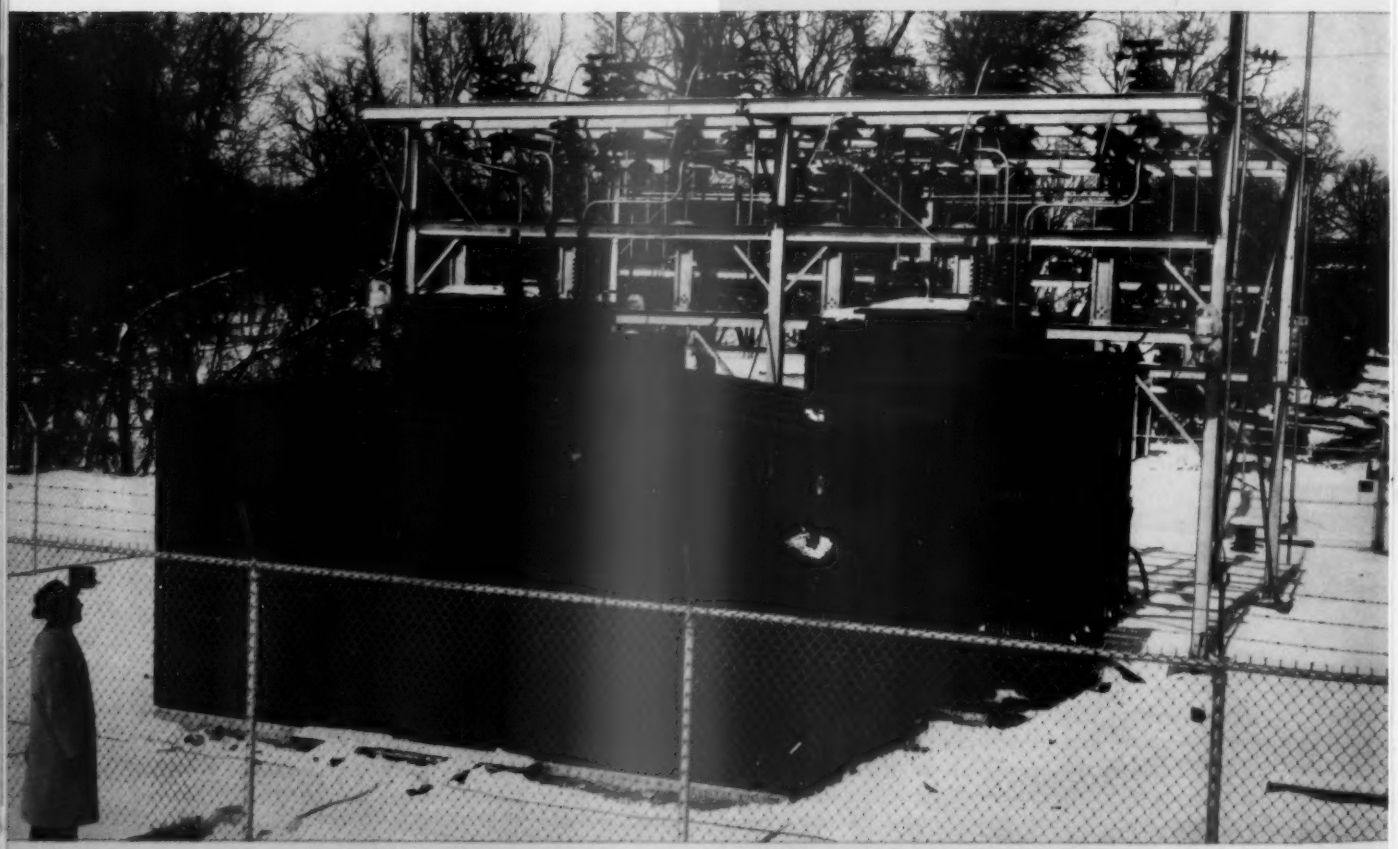
Switchgear weatherproofing is assured

Although the test performed on these switchgear units was considered more rugged than a severe rainstorm, it was a fair test for the equipment. To reduce the severity of the test would do little to simplify the design problems involved in making switchgear equipment weatherproof. The test indicated that the equipment will withstand unusual weather conditions.

As a result of this test and similar ones, weatherproofing standards have been set up by NEMA for power switchgear assemblies. They assure the user that outdoor switchgear equipment is capable of safe and dependable service in prolonged exposures to all types of weather.



DRY, CLEAR AREA is provided for operators. Standard indoor gear is fully weather protected and horizontal drawout circuit breakers can be withdrawn and checked with ease on smooth flooring.



OUTDOOR SWITCHGEAR ENCLOSURES must provide protection against all weather conditions. Common sheltered aisle is provided between facing 4.16-kv switchgear groups in double-ended substation.

CONTROLLING DIODE RECTIFIER OUTPUT

by **FRANK H. LADD**
Regulator Department
Allis-Chalmers Mfg. Co.

New voltage regulator provides needed control for diode type industrial power rectifier units.

THE RAPIDLY GROWING electro chemical industry, a major user of dc power, not only requires good regulation but also a range of dc operating voltages. Since these processes require a variable voltage and since the diode type rectifiers are not controllable, the voltage supplied to these rectifiers is controlled with a new type voltage regulator.

The close voltage regulation provides more accurate process control and serves to protect the rectifier from overvoltage.

A similar voltage control of diode type rectifiers is used in nuclear fusion studies. The regulator controls the voltage to the rectifier transformer primary and the range of regulator voltage output is from 0 to 105.6 percent voltage instead of the normal range of plus or minus 10 percent regulation used in process control. This regulator is designed to carry 1000 through kva, 41.8 amps at 13,800 volts and operates at various points from 0 to 105.6 percent voltage output continuously. The regulator maintains the output voltage within ½ percent at any point over the entire voltage range. The time required per tap change is less than one second.

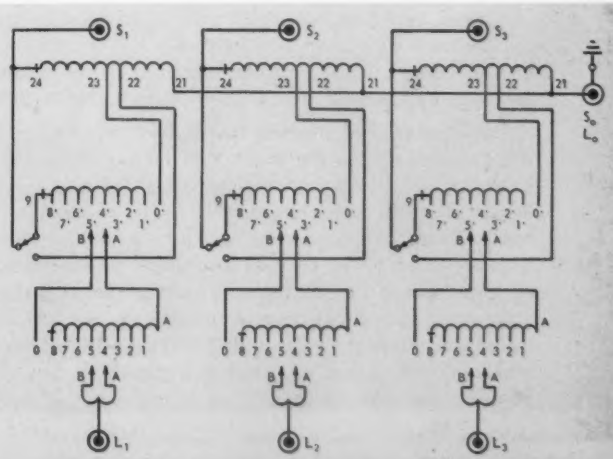
The combination of windings shown in Figure 1 was used to obtain the wide range regulation needed. All windings were on the same core. The turns in the various windings were so arranged that voltage of section 1′-8′ equalled 43¾ percent of the total buck range of the regulator, the voltage of section 23-24 equalled 50 percent of the total buck range, and the voltage of section 22-23 equalled 6¼ percent of the total buck range. The tapped section 1′-8′ was arranged so that it could be connected to point 24 or point 22 by a reversing switch, effectively doubling the range of this winding. This reversing can take place only when the two moving fingers, A & B, are on contact 0′ so that there is no interruption of current by the switch.

With this combination of windings and voltages, variation in output voltage was obtained in uniform steps.

The third winding, A-8, served as a vernier winding across any one of the tap sections of the winding 1′-8′ giving a fine step to this inherently large step unit. The voltage of this third winding was 5/8 of the voltage of one of the tap sections of winding 1′-8′. The void between contacts 0 and 8 of this winding reduced its size and increased the flexibility of changing the moving fingers on winding 1′-8′. It also provided a small amount of regulation in the boost direction.

The tap changing under load equipment incorporated into this unit consisted of a fine step mechanism connected to winding A-8 having 0.35 percent steps and 18 positions and a coarse step mechanism connected to winding 1′-8′ having 3.13 percent steps and 33 positions. Through the automatic control of these combined mechanisms, the output voltage of the regulator could be held constant. Through manual control, the output voltage at rated load current could be changed from 0 to 105.6 percent of rated voltage in 304 fine steps. Alternatively, the output voltage could be changed from 0 to 100 percent of rated voltage in 32 coarse steps or in combinations of coarse and fine steps thus giving considerable flexibility in speed and increment of voltage change.

Where control of diode type rectifier units is required, step type regulators can provide a variable input voltage in any range desired with regulation of this voltage within close tolerances. Dc supply voltages controlled in this manner are now serving a variety of processes in the electro chemical and other industries as well as in the research field. The economy of obtaining controlled dc power with silicon and germanium diodes has made this arrangement attractive.

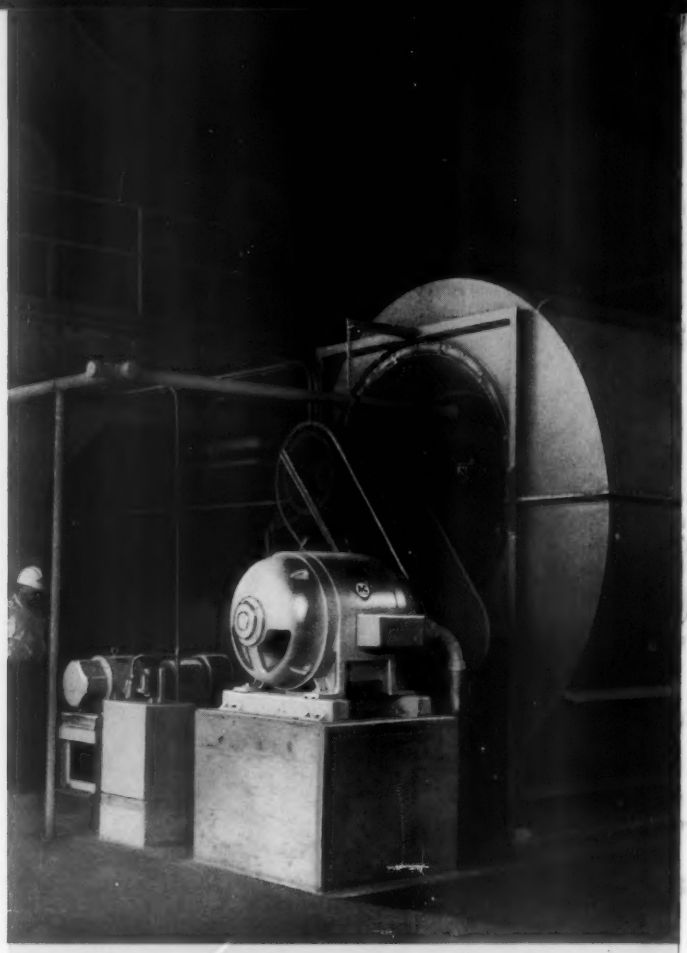


CIRCUIT can provide ½ percent regulation at any point between 0 and 105.6 percent voltage for control of diode type rectifiers. **(FIGURE 1)**

Wk^2 VS ROTOR LOSS

by R. C. MOORE
Motor and Generator Dept.
Allis-Chalmers Mfg. Co.

The relation between rotor loss and Wk^2 becomes important when accelerating, decelerating or plugging induction motors driving high inertia loads. Here are basic considerations.



MOTOR ROTOR DAMAGE can be averted when information on rotor energy loss during acceleration of a high inertia load is available. The centrifugal blower in a large cement plant is such a load.

BECAUSE THE ACCELERATING TIME may be long for high inertia (Wk^2) loads, protection and control of the motor need careful appraisal. While motor stators may be suitably protected, commercial devices have not been available to directly protect a motor rotor subjected to the abnormally high energy losses accompanying high inertia loads.

The energy loss in the cage or starting windings of standard induction and synchronous motors starting inertia loads can cause the windings and adjacent iron to reach damaging temperatures. However, helpful application information, outlining load Wk^2 values and starting procedures for a wide range of horsepower and speed ratings of induction motors, may be obtained from NEMA Motor and Generator Standards, Publication MG-1-1959.

Formulas derived may be useful in computing rotor energy losses during the starting of inertia loads. Tests show that when load torque is negligible, the total energy loss in a rotor during starting is equal to the kinetic energy stored in the rotating parts at synchronous speed. This equivalence may be used to simplify the calculation of rotor energy loss during the starting period and to make rotor energy loss comparisons during complete and incomplete starting, plugging and braking. The effect of load torque on rotor loss during acceleration may also be developed.

Rotor power loss computed

When the rotor slips with respect to the synchronous rotating magnetic field produced by the stator winding, currents induced in the rotor winding are the source of rotor I^2R loss. For a particular rotor slip speed the rotor I^2R power loss may be obtained from the mechanical analogy of a friction clutch, shown in Figure 1.

In Figure 1 a torque, T, is transmitted through the clutch. Input power to the clutch may be calculated from the following horsepower expression:

$$\text{Hp input} = \frac{TN}{5252}$$

where T = torque, lb-ft.

N = synchronous speed, revolutions per minute of the left-hand member of the clutch in Figure 1.

The efficiency of power transmission of the clutch may be calculated as

$$\text{Efficiency} = \frac{\text{Hp output}}{\text{Hp input}} = \frac{TN_a/5252}{TN/5252} = \frac{N_a}{N} = \frac{N(1-s)}{N} = 1 - s$$

where N_a = actual speed of right-hand member, Figure 1, in rpm.

s = slip between the two rotating members.
= difference rpm/synchronous rpm.

The horsepower output of the friction clutch is, therefore, $TN\ (1-s)/5252$, and the horsepower loss in power transmission through the clutch is the difference between input and output, or

$$\text{Loss} = \frac{TN}{5252} - \frac{TN\ (1-s)}{5252} = \frac{TNs}{5252}$$

Slip loss in the starting windings of synchronous or induction motors is represented by the same formula, so that

$$\text{Kw rotor loss} = \frac{T_m N s}{5252} \times .746 = \frac{T_m N s}{7040}$$
$$= 3I^2R \text{ (three-phase motor)}$$

where I and R are rotor current and resistance, respectively, and T_m is motor shaft torque.

Rotor energy loss may be derived

During accelerating time t, rotor energy loss may be expressed as power multiplied by time, that is, I^2Rt. For a small change in time, dt, rotor energy loss, dL, is

$$dL = \frac{T_m N s}{7040}\, dt = 3I^2R\ dt \qquad (1)$$

The time to accelerate an inertia Wk^2 (lb-ft^2) to a given speed may be obtained from Eq. (2):

$$t = \frac{Wk^2\ N\ (1-s)}{308\ (T_m - T_L)}, \text{ seconds} \qquad (2)$$

where T_L is load torque in lb-ft. Thus $T_m - T_L$ represents the motor torque available to accelerate the Wk^2 of the motor and load. From Eq. (2)

$$dt = -\frac{Wk^2\ N}{308\ (T_m - T_L)}\, ds$$

The expression for dt may be substituted in Eq. (1) and

$$dL = 3I^2R\ dt = -\frac{T_m\ N^2 s}{7040} \times \frac{Wk^2\ ds}{308\ (T_m - T_L)}$$
$$= -\frac{T_m}{T_m - T_L} \times \frac{Wk^2\ N^2}{.217 \times 10^7} \times s\ ds$$

and integrating, to determine rotor loss between two values of slip s_1 and s_2,

$$\text{Rotor loss} = dL = \frac{2.31\ Wk^2\ N^2\ (s_1^2 - s_2^2)}{107} \times \frac{T_m}{T_m - T_L}, \text{ kw-sec} \qquad (3)$$

where N = synchronous speed and s_1, s_2 = slip, decimal values.

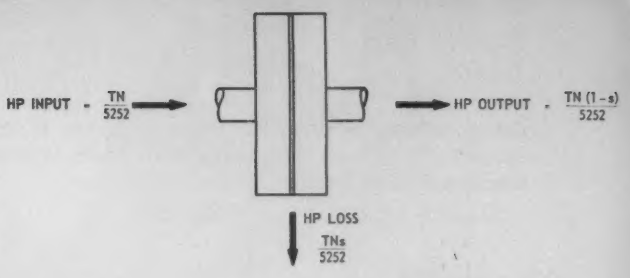
When a motor and its connected load inertia start from rest, $s_2 = 0$. Hence, when full speed is reached, the energy loss in the rotor starting winding is, from Eq. (3),

$$\text{Rotor energy loss} = 2.31\ Wk^2\ N^2 \frac{T_m}{T_m - T_L}\, 10^{-7}, \text{ kw-sec} \qquad (4)$$

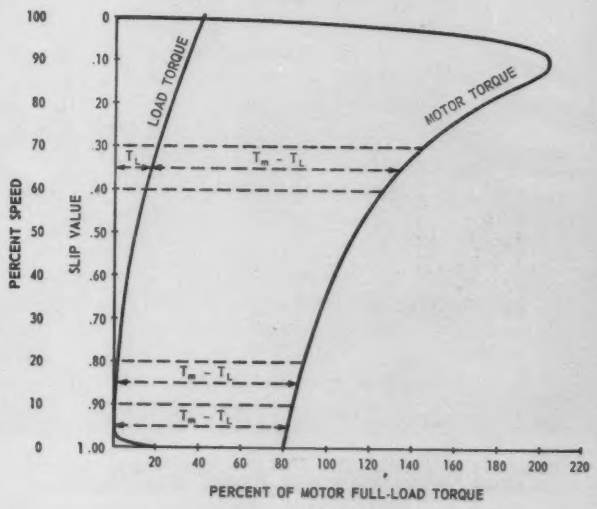
where N = synchronous speed.

Rotor energy loss equals kinetic energy stored in rotor

The rotor energy loss in the starting winding of a motor which has accelerated an inertia to full speed may be shown equal to the kinetic energy stored in the rotating parts at synchronous speed, provided the load torque



FRICTION CLUTCH serves as analogy in determining rotor loss. **(FIGURE 1)**



MOTOR TORQUE available is reduced by load torque requirement. **(FIGURE 2)**

SELECTION of conveyor belt drive motor requires careful consideration of the maximum possible load inertia that must be accelerated.

during starting is negligible. A development of this equality may be made using the formula which expresses kinetic energy in a rotating body, that is,

$$\text{Kinetic energy} = \tfrac{1}{2} J w^2, \text{ foot-pounds}$$

$$= \frac{Wk^2}{2g} \times \left[\frac{2\pi \text{rpm}}{60}\right]^2$$

where J = polar moment of inertia = Wk^2/g.
W = weight of rotating parts, lb.
k = radius of gyration of rotating parts, feet.
g = gravity constant, 32.2.
w = angular velocity of rotating parts at synchronous speed, radians per second.
rpm = revolutions per minute of rotating parts at synchronous speed.

Carrying out the computation of the preceding equation, it may be found that

$$\text{Kinetic energy} = 1.704\ Wk^2\ \text{rpm}^2\ 10^{-4} \text{ foot-pounds}$$
$$= 2.31\ \ Wk^2\ \text{rpm}^2\ 10^{-7} \text{ kw-sec.} \qquad (5)$$

Equation (5) is the same as Eq. (4) when the load torque requirements are negligible. Thus the equivalence that motor rotor energy loss equals energy stored in the rotating parts is valid only when the accelerating range is from standstill to synchronous speed and load torque is negligible. With an incomplete motor start, or plugging duty, Eq. (3) is used.

Load torque increases motor rotor losses

Equations (4) and (5) indicate that motor rotor losses during acceleration of connected loads may be determined, as shown above, from the kinetic energy formula of Eq. (5) only when load torque, T_L, is negligible. When load torque becomes significant, its effect is to introduce the factor $T_m/T_m - T_L$ in Eq. (5), which then becomes Eq. (4). The factor is usually greater than unity.

Curves of motor and load torque in Figure 2 show that both T_m, the motor torque, and $T_m - T_L$, the motor torque less the load torque, vary with speed. An experienced engineer may choose to ignore T_L in some applications when he considers it sufficiently small compared to T_m. In other applications he may consider T_L to be significant and may closely estimate, from experience, a single value of the ratio $T_m/T_m - T_L$ to use for the entire range from standstill to full speed. Thus Eq. (5) may then be used with the single factor applied.

In still other applications the engineer may decide to calculate rotor loss using Eq. (3), because T_L is appreciable and variable compared to T_m during the overall accelerating period to full speed. The following method illustrates a procedure which may be followed when Eq. (3) is used to predict rotor losses during acceleration.

In Figure 2 a slip speed interval $s_1 = 1.0$ to $s_2 = 0.90$ Eq. (3), may be chosen and the average torque, $T_m - T_L$, at the midpoint $s = 0.95$ may be assumed to apply. Motor torque, T_m, may be taken from the motor torque curve at $s = 0.95$. Thus the ratio $T_m/T_m - T_L$ may then be used in Eq. (3) to calculate the rotor loss, L_1, when 10 percent speed is reached ($s = 0.90$). Figure 2 shows that T_L may be insignificant at low speeds, that is, at high slip values.

In the second step, the second speed interval may be chosen from $s_1 = 0.90$ to $s_2 = 0.80$, evaluating T_m and T_L at the midpoint slip value of $s = 0.85$. Equation (3) may be used to calculate the rotor loss, L_2. Thus the rotor loss from standstill to 20 percent speed ($s = 0.80$) is the sum of L_1 and L_2.

For the third step, the speed interval is chosen as $s_1 = 0.80$ and $s_2 = 0.70$. Successive steps at 0.10 slip intervals may be chosen until full speed is reached. When $s_1 = 0.40$ and $s_2 = 0.30$ as in Figure 2, the load torque, T_L, may become appreciable and the ratio $T_m/T_m - T_L$ may become significant at the higher speed, lower slip, values.

Total rotor loss during acceleration may now be obtained by summing all computed rotor loss values L_1, L_2, L_3, etc.

Multispeed motor starting reduces rotor energy loss

A reduction in motor rotor energy loss is obtained if an inertia load is accelerated to a required speed in two or more steps using a multispeed induction motor instead of a single-speed induction motor. Thus a two-speed induction motor of, say, 2:1 speed ratio may be used to accelerate an inertia Wk^2 to half the required full speed on the low speed connection and from half to full speed on the high speed connection.

Rotor energy loss reduction obtained by using a two-speed instead of a single-speed motor is illustrated by the following example in which the influence of load torque during acceleration is neglected to simplify the discussion. If desired, the influence of load torque may be included as shown in the previously developed formulas.

When started on the high speed connection only, the motor accelerated an inertia Wk^2 to full speed with a rotor energy loss calculated from Eq. (5) to be 100 percent, that is,

$$\text{Rotor energy loss} = 2.31\ Wk^2\ \text{rpm}^2\ 10^{-7} = 100 \text{ percent}$$

Assuming that two-speed type induction motor starting is used, the motor may be started first on the low speed connection to attain half of the desired full speed with a rotor energy loss calculated by Eq. (5),

$$\text{Rotor energy loss to half speed} = 2.31\ Wk^2\ \frac{\text{rpm}^2}{4}$$
$$10^{-7} = 25 \text{ percent}$$

The inertia may then be accelerated from half speed to full speed on the high speed winding connection so that the additional rotor energy loss may be calculated from Eq. (3),

$$\text{Rotor energy loss from half to full speed} =$$
$$2.31\ Wk^2\ \text{rpm}^2\ (0.50^2 - 0) = 25 \text{ percent}$$

The total rotor energy loss when accelerating the inertia to full speed using a two-speed motor of 2:1 speed ratio is, therefore, only 50 percent of the rotor energy loss for a single-speed starting method.

Speed references in evaluation energy losses are important

When a motor is direct-connected to the driven inertia

so that they both run at the same speed, the motor, coupling, load, etc., inertias, that is, the Wk^2 values of each part, may be arithmetically added together to obtain a sum Wk^2. The formulas derived may then be applied using the sum Wk^2.

In some applications the load inertia Wk^2 is geared or belted to the driving motor and the motor and load inertias run at different speeds. Since individual inertias, or Wk^2 values, may not be directly added arithmetically, two procedures are available to handle such cases.

(*a*) The kinetic energy of all high speed rotating inertias and similarly of all low speed rotating inertias may each be independently calculated from Eq. (5). By adding together the calculated energies for each speed system, the total kinetic energy which represents motor rotor energy loss may be obtained,

(*b*) An alternative method to calculate the total kinetic energy of two connected systems running at different speeds is to refer all Wk^2 values to a common speed so that formulas such as Eq. (5) may be applied. If the motor inertia $(Wk^2)_1$ rotates at speed $(\text{rpm})_1$ and the load $(Wk^2)_2$ rotates at $(\text{rpm})_2$, then

$$(Wk^2)'_2 = (Wk^2)_2 \text{ referred to } (\text{rpm})_1 = \frac{(\text{rpm})^2_2}{(\text{rpm})^2_1} \times (Wk^2)_2$$

The total Wk^2 at $(\text{rpm})_1$ is then $(Wk^2)_1$ added arithmetically to $(Wk^2)'_2$. Equation (5) may then be used to calculate the kinetic energy for the complete system using the total Wk^2 and $(\text{rpm})_1$.

Formulas applied

The use of Eq. (5) to determine rotor energy loss during a change in speed may be illustrated by the following examples in which the load torque, T_L, is assumed negligible:

a) The rotor energy loss for a speed change from slip $s_1 = 1$ (standstill) to $s = 0$ (synchronous speed) is from Eq. (5): $\text{kw-sec} = 2.31\ Wk^2\ \text{rpm}^2\ 10^{-7}$ where rpm is synchronous speed.

b) Rotor energy loss may also be determined for other speed ranges. For example, for a plug stop from a reverse full speed, $s = 2$, when two power lines to the motor are interchanged, to $s = 1$, standstill, Eq. (3) may be used to calculate:

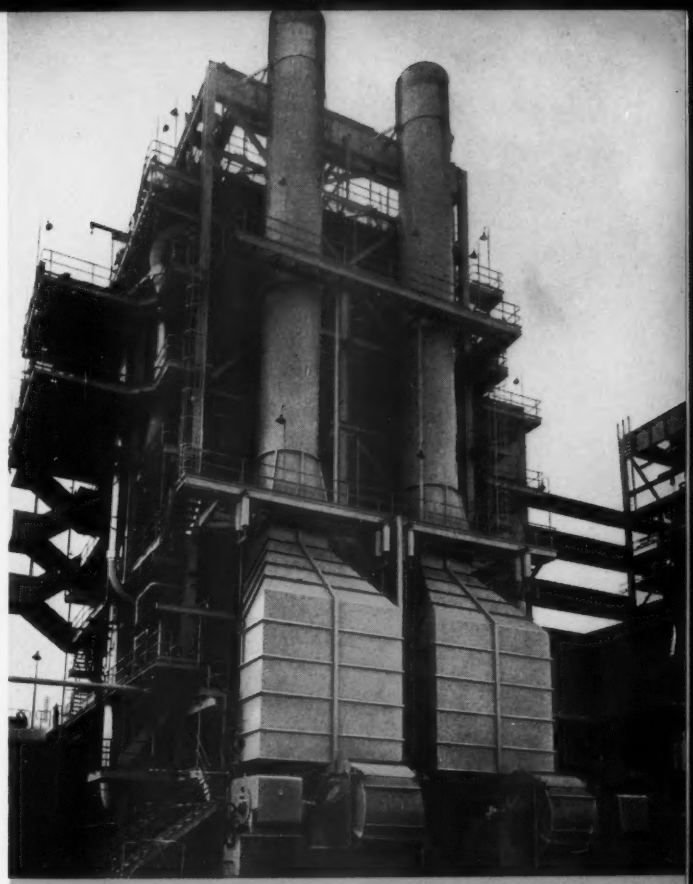
$$\text{kw-sec} = .31\ Wk^2\ \text{rpm}^2\ (4-1) = 2.31\ Wk^2\ \text{rpm}^2\ 10^{-7} \times 3$$

which shows that the energy loss in the rotor of a motor is 3 times the rotor loss occurring in accelerating the inertia load from standstill to full speed.

c) Another type of operation may occur when a motor is plugged by interchanging two power lines to the motor at full reverse speed, $s = 2$, to standstill and then allow the motor to accelerate to full speed where $s = 0$. From Eq. (5) the rotor energy loss is

$$\text{kw-sec} = 2.31\ Wk^2\ \text{rpm}^2\ (4-0) = 2.31\ Wk^2\ \text{rpm}^2 \times 4$$

which indicates that the rotor energy loss is 4 times that occurring in accelerating the inertia load from standstill to full speed.



FORCED DRAFT FANS in Southwestern power plant are typical high inertia loads. The fans are driven by 700-hp, 1182-rpm motors.

d) An incompleted start where the power supply is removed from the motor before full speed is attained may result in rotor energy loss which is nearly as much as a completed start. For example, if the power supply is removed from the motor at half speed, $s = 0.5$, or at three quarters speed, $s = 0.25$, the rotor energy loss calculated by Eq. (3) is 75 percent and 94 percent, respectively, of the rotor energy loss for a completed start.

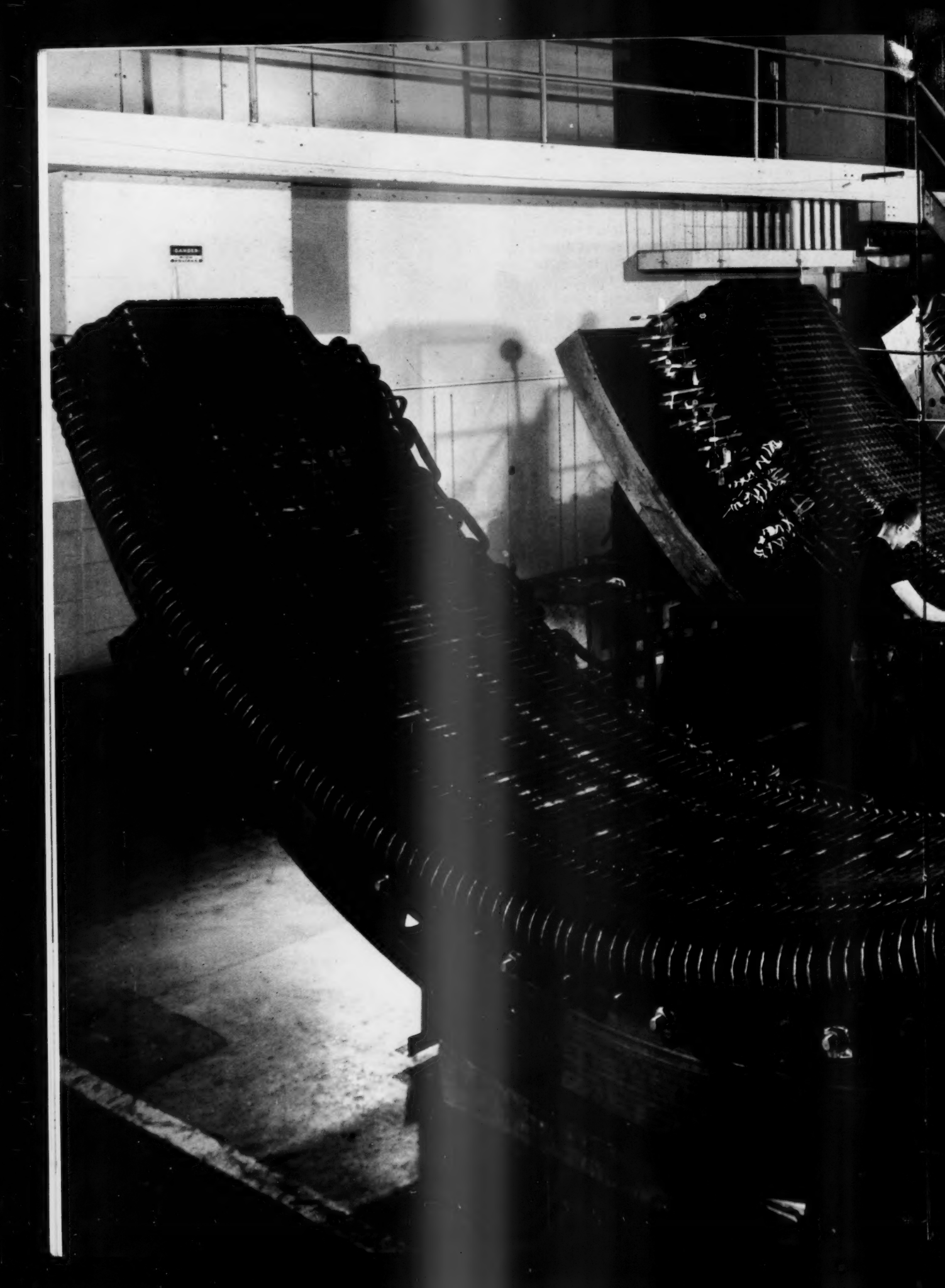
In many calculations an assumption may be made that $s = 0$, or that synchronous speed is reached in applying the formulas to determine rotor energy loss. An induction motor normally reaches a speed slightly less than synchronous speed. However, the full-speed slip is so small in the usual case that little error is made in assuming $s = 0$ in the calculations.

By using the formulas developed for Wk^2 loads, computations may be readily made to determine rotor starting losses. Calculations are used to predict rotor losses for complete or incomplete starting, geared Wk^2 loads and braking, to obtain comparisons which may be helpful for different problems arising in motor applications.

REFERENCES

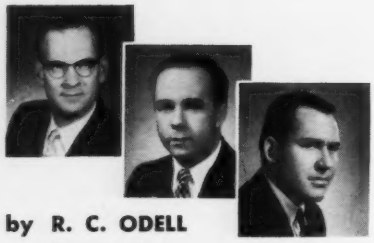
1. "Synchronous Motor Torques Defined," *Allis-Chalmers Electrical Review*, 3rd Quarter, 1959.
2. "Induction Motor Temperature Characteristics," J. F. Heidbreder, AIEE Conference Paper, 55-761.

GENERATOR-MOTOR STATOR, one of twelve, for New York State Power Authority's Tuscarora pump-turbine project on the Niagara River is divided into 3 sections for shipping. Rated 25,000 kva as a generator and 37,500 hp as a motor, the 112½-rpm unit uses approximately 60 miles of copper wire in its winding. The stator will be about 30 feet in diameter and 5 feet high when assembled at the site.
Allis-Chalmers Staff Photo by Michael Durante



VACUUM SWITCH For Controlling Reactive Power

VACUUM INTERRUPTER provides new approach to capacitor bank switching. Three of these switches are simultaneously operated from single mechanism for three-phase switching.



by R. C. ODELL
Capacitor Section
Regulator Department
and
H. M. PFLANZ and G. N. LESTER
Boston Works
Allis-Chalmers Mfg. Co.

New vacuum switches, designed for repetitive duty, provide dependable service in switching substation capacitor banks.

BANKS OF STATIC CAPACITORS are being applied in increasing number as sources of reactive kilovars to supply the growing inductive reactance requirements of electrical distribution systems. In applying capacitors, distribution engineers think of the ensuing benefits of general system improvement because of increased power factor, improved voltage regulation condition, or the gain in extra kilowatts of generator, line or substation capacity. The utility economist thinks in terms of extra dollars of revenue from the sale of more kilowatts from a given generator, line, or transformer.

Generally speaking, the greatest benefits are obtained by locating capacitors close to the actual load centers. These installations are usually in the form of pole top capacitor banks rated 300 to 1200 kvar. However, as distribution lines become "filled" with capacitors, they are installed in distribution substations. Here, capacitors are mounted or stacked in open racks or in enclosures. Maximum benefit from the capacitors is obtained by switching them on or off the system in response to line or load conditions. Switching may be initiated by system operators monitoring load reactive requirements or by automatic control devices operating on a basis of time, voltage, current, kilovars, or a combination of these factors.

Overall average utility surveys show that approximately 60 percent of the installed capacitive kvar is switched. About 25 percent of the switched capacitors are installed on pole tops, 60 percent in 5 to 15-kv substations and 15 percent in station banks above 15 kv.

Switching of pole top banks is accomplished by means of small, single phase oil switches generally mounted on the same racks supporting the capacitors. Such switches may be called upon to operate several times a day and must be suitable for many thousands of operations. Usually they operate well within their rating and have low maintenance requirements. Because of their light weight they are easily replaced in the field when the occasion demands.

Switching equipment varies

As switching devices for large capacitor banks, 15 kv and above, circuit breakers have usually been applied. For switching banks of 7500 kvar and below at voltages up to 15 kv, three-phase oil switches have frequently been applied although not ideally suited to the purpose. The new, three-phase, vacuum capacitor switch, rated 300 amperes, is intended to fulfill the requirements for economical and dependable capacitor switching service for banks of these ratings.

Two basic factors affecting the design of any capacitor switching device are:

1) The recovery voltage following interruption of the 60 cycle capacitor current.
2) The high frequency inrush current occuring when energizing a capacitor bank or when restrikes or reignitions occur if there is an energized parallel capacitor bank close to the bank being switched.

The recovery voltage conditions existing during a capacitive current switching operation are shown in Figure 1. The simple circuit shown could be one phase of a grounded 3-phase capacitor bank. While the switch is closed, the current leads the voltage by 90 degrees and the capacitor is charged to the generator voltage value. When the switch contacts separate at t_0, an arc is initiated that exists until the next 60 cycle current zero at t_1. At this moment the current is zero and the voltage across the switch is almost zero since the capacitor retains the

charge of peak voltage which existed at current zero. The system voltage drops slightly, indicating the regulation of the system when the capacitors are removed. This voltage change, usually only a few percent of system voltage, is determined by the kvar of the capacitor bank and the short circuit kva possible from the system.

$$\text{Voltage change } (\Delta e) \cong \frac{\text{kvar}}{\text{kva (s.c.)}} \times 100 \text{ percent}$$

Following the circuit interruption at t_1, the capacitor retains the charge of crest voltage but the system reverses polarity in the next one-half cycle, imposing two times crest voltage across the switch contacts as shown at t_2. After t_2 the system voltage reverses polarity, reducing the voltage difference across the contacts. Continued opening of the contact gap reduces the actual voltage stress on the gap at the next half cycle interval.

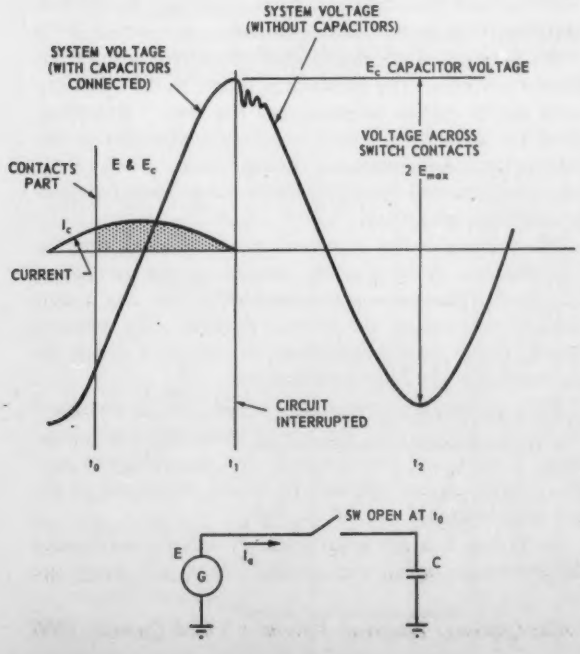
If the dielectric strength of the contact gap is not sufficient during the time between t_1 and t_2 to withstand the increasing recovery voltage, a breakdown (restrike or reignition) may occur. Figure 2 illustrates the theoretically maximum possible voltage conditions in a circuit if a restrike occurs at t_2, the time of the highest voltage stress. This condition results in the capacitor suddenly discharging into the system and its voltage being brought to the opposite polarity of the system. This voltage overshoots the system voltage by an equal amount and at the first current zero of the transient restrike current may leave the capacitor charged to a potential of $-3\ E_{max}$. If further restrikes should occur, higher transient voltages could result in flashover on the capacitors, the switching device, or the system.

Other capacitance circuit configurations from the grounded capacitor bank, grounded system case described can produce more severe recovery voltage conditions for the switch. Where the circuit described above imposed a maximum recovery voltage crest on the switch of $2\ E_{max}$, a switch disconnecting an unloaded transmission line will experience $2.4\ E_{max}$ in the first phase to interrupt. A switch in a circuit where either the capacitor bank or the system, or both are ungrounded will have a recovery voltage of $3\ E_{max}$ in the first phase to interrupt. If the contacts in each phase of the switch do not open at essentially the same time, that is, with variation of more than approximately one quarter cycle, as can occur particularly with three single-phase switches not mechanically interconnected, even higher recovery voltages can appear in the first phase interrupting. In an ungrounded circuit, with certain delays in opening of the second pole the recovery voltage on the first pole can be as high as $4.1\ E_{max}$.[3]

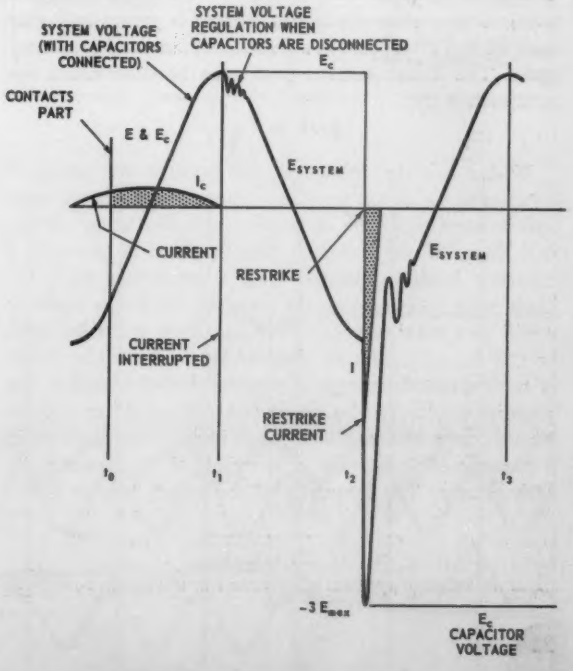
Restrike free performance assured

In the new three-phase vacuum capacitor switch the extremely rapid dielectric recovery characteristics following interruption of capacitance currents assures restrike free performance. In hundreds of tests with voltages of grounded and ungrounded conditions, not a single restrike was observed making this switch ideally suited for capacitor bank switching applications. The operation of the switch mechanism provides simultaneous contact parting in each phase avoiding the possibility of excessive recovery voltages associated with non-simultaneous opening.

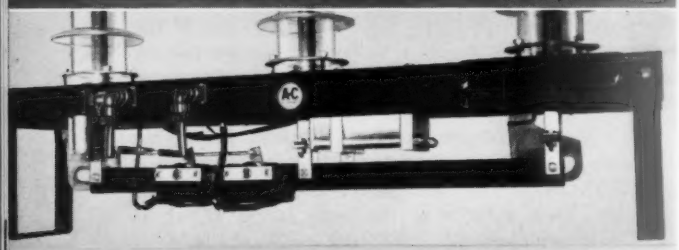
The high frequency, oscillatory, inrush current possible when one bank is closely paralleled by a second bank is basically determined by the capacitor bank size, the voltage conditions on the banks at the moment the circuit is established or re-established, and the impedance between the banks. Completion of the circuit may be through prestrike or contact touch during closing or through reignition or restrike during opening. Because of resis-



VOLTAGE across switch contacts reaches twice maximum system voltage because of charge remaining on capacitors. **(FIGURE 1)**



FAST DIELECTRIC RECOVERY prevents restrike and resulting severe transiet voltage conditions across the switch. **(FIGURE 2)**



CAPACITIVE SWITCHING CURRENTS of 300 amperes are handled by 3-phase, 15-kv vacuum switch for capacitor banks. **(FIGURE 3)**

OPENING AND CLOSING SOLENOID operates cams for moving horizontal operating bar vertically to actuate interrupters. **(FIGURE 4)**

tance in the circuit the inrush current is generally highly damped and disappears in a fraction of a normal frequency cycle. The inrush current peak may be determined approximately by:

$$i\ \text{peak} = e\sqrt{\frac{C_T}{L_T}}$$

Where e is the voltage at the moment the circuit is completed, C_T is the total capacitance and L_T is the total inductance around the circuit through which the current will flow. If the circuit is simply closed to energize a capacitor bank in parallel with a previously energized bank, with no charge on the switched bank, the value of e will be a maximum of $\sqrt{2}\ E_{phase}$ for a grounded bank or $\sqrt{2}\ E_{line\text{-}to\text{-}line}$, for an ungrounded bank. If the circuit is re-established through a restrike during opening, the magnitude of e can be up to twice these values because of the charge left on the switched bank. This could mean a corresponding increase in the peak of the transient inrush current. The frequency of the inrush current is:

$$f_0 = \frac{1}{2\pi\sqrt{C_T L_T}}$$

In an average application where the inductance between parallel capacitor banks amounts to 15 to 30 microhenries the inrush current peak can be many thousands of amperes with a natural frequency of 3 to 10 kilocycles. The result of this discharge of current if it occurs as a prestrike on closing the switch or as a restrike can be increased contact erosion beyond normal arcing wear and possibly even damage to the switch from the pressure generated (in oil switches). A device which has fast contact closing or high dielectric strength between contacts will limit prestriking to a minimum and reduce or eliminate this excessive contact wear. The dielectric characteristics of the switch during opening will determine whether restrikes can occur.

When a capacitor bank is energized there is also a component of inrush current from the system. This current, however, is limited by the source inductance and is much lower in magnitude and natural frequency than the inrush current possible from a parallel bank.

The high dielectric strength of the vacuum interrupter effectively limits prestrike on closing to a minimum and eliminates restrikes on opening, assuring long interrupter life even in parallel bank application.

Single mechanism for three phases

The new vacuum switch, shown in Figures 3 and 4, consists of three phase columns mounted on a compact mechanism cabinet. The upper section of each of the columns houses a permanently sealed vacuum interrupter. The electrical terminals of the switch are located at the top and in the center of the ¼ inch thick, transparent, weather resistant plastic column. In the lower section of the column is the operating rod connecting the movable contact of the interrupter to the mechanism. The mechanism in the switch illustrated, is basically composed of a combination opening and closing solenoid which moves a horizontal linkage system to rotate two slotted cams, located at the ends of the mechanism cabinet. These cams move a horizontal operating bar in a vertical direction to actuate the interrupter contacts through the vertical operating rods in each phase column.

On the right of the mechanism cabinet the position indicator is visible. The indicator is linked to the operating cams and is used as an emergency trip lever. Extending from the left of the position indicator assembly is the emergency and maintenance closing handle. Both of the emergency manual operating levers are notched for operating with a hook-stick.

The vacuum switch is opened either by energizing the trip solenoid, or by pushing upward on the emergency trip lever. The cams are rotated until the cam rollers have moved out of the latched position. The opening spring, acting on the horizontal tie rod, then drives the mechanism to the fully open position.

Both closing and opening solenoids are de-energized by cutoff switches near the end of their respective operation. These cutoff switches, and also the additional auxiliary switches, are operated by a link connected to the left-hand cam.

In Figure 5 is the interrupter. A bellows, surrounded by a tube, to which the metallic shield and flange are

fastened, provides a flexible seal between the movable contact member and the base of the interrupter. The ⅝ inch diameter contacts, tipped with a highly arc resistant metal such as tungsten, are enveloped by a metallic electrostatic shield, electrically connected to the movable electrode. This shield prevents metallic vapors from precipitating on the glass envelope. Because this shield is thoroughly outgassed along with the contact members, it will tend to maintain the proper degree of vacuum in the tube, as would a diffusion pump, by trapping and immobilizing the gasses as well as the metallic vapors released from the contacts during interruption.

During the course of the development of the vacuum switch extensive tests were made to prove its design qualifications. Included in the tests was a mechanical life test on a 3-phase switch taken from the production line and subjected to 15,000 close-open operations. No significant wear on any mechanical members appeared and no maintenance was required. In additional tests the plastic housing was subjected to close range, 22 caliber, rifle fire without being penetrated.

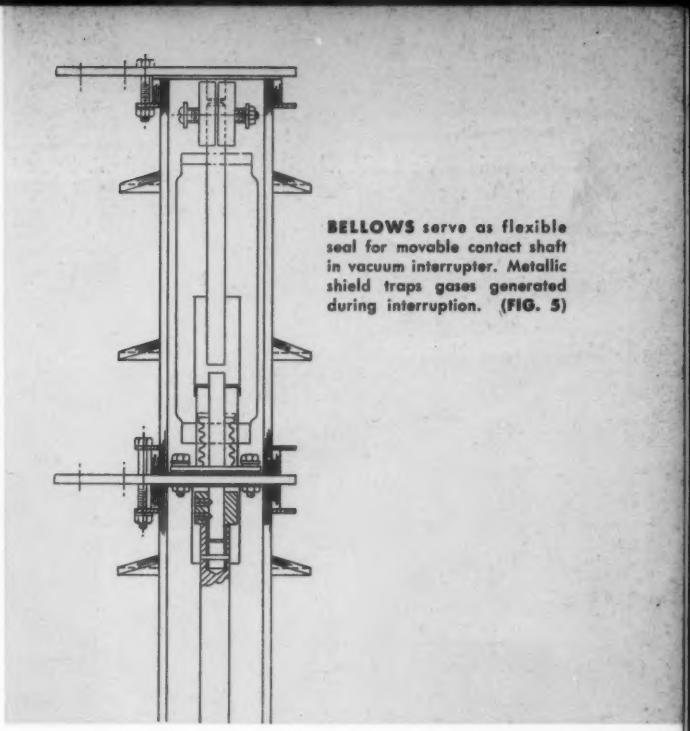
An oscillogram of a typical operation during a single phase 1300 operation test is shown in Figure 6. A tabulation of the switch characteristics and ratings is shown in Table I.

Field experience has been gained with an initial model of the vacuum capacitor switch installed on the system of a Southern utility since January 1958. This switch has operated satisfactorily and has required no maintenance.

As the need for switched capacitor banks in substations grows, the new vacuum type switches will provide an economical answer to controlling reactive power within their ratings.

REFERENCES

1. "A 15-KV Vacuum Capacitor Switch" — Development and Field Experience," H. B. Balfour, H. M. Pflanz, G. N. Lester, AIEE Conference Paper 59-100.
2. "A 15-KV Vacuum Capacitor Switch," H. B. Balfour, H. M. Pflanz, G. N. Lester, *Proceedings* American Power Conference, 1959, Chicago, Illinois, Pages 593-600.
3. "Some Fundamentals on Capacitance Switching," I. B. Johnson, A. J. Schultz, N. R. Schultz, R. B. Shores, AIEE *Transactions,* Volume 74, Part III, 1955, Pages 727-736.

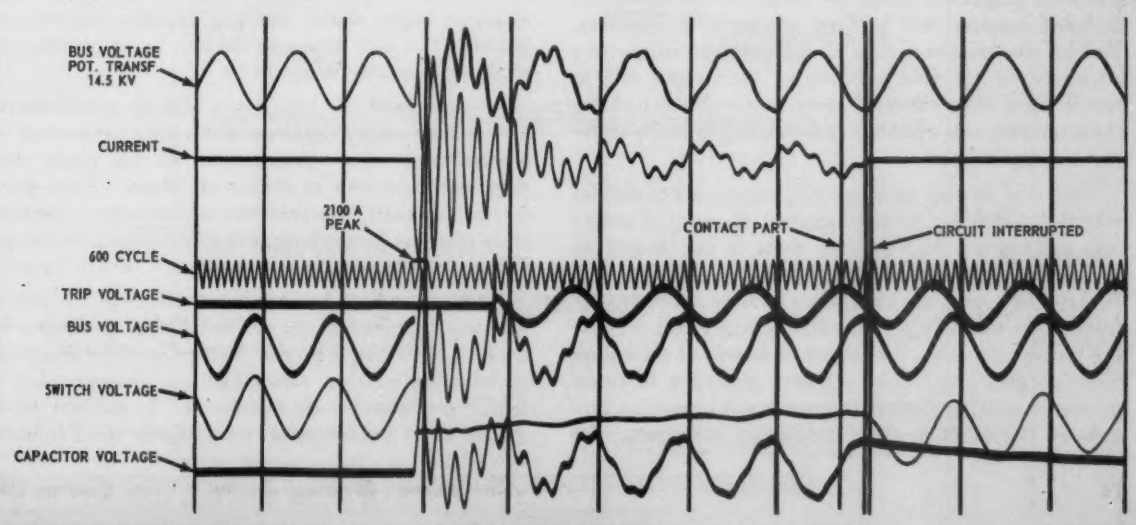


BELLOWS serve as flexible seal for movable contact shaft in vacuum interrupter. Metallic shield traps gases generated during interruption. **(FIG. 5)**

TABLE I

VACUUM SWITCH CHARACTERISTICS

Rated Volts	14.4 kv
60 cycle, one minute withstand	50 kv
Impulse Withstand, 1.5 x 40 sec. wave	95 kv (indoor) 110 kv (outdoor)
Thermal Current	400 amp.
Capacitive Switching Current	300 amp.
Momentary Current	20,000 amp.
Two-second Through Current	12,500 amp.
Application	Outdoor or Indoor
Operation	Electrical (for normal close and open) Manual (for emergency close and open)
Control voltage	125 vdc or 120 vac
Auxiliary Stages	Four (two of which are for solenoid cut-off). Total of eight can be furnished.



INTERRUPTION TEST oscillogram shows current and voltage fluctuations when vacuum switch opens 255-ampere capacitor circuit. **(FIGURE 6)**

IMPROVE PERFORMANCE *with* COOPERATIVE PLANNING

by **W. C. FRAZIER**
Steam Turbine Department
Allis-Chalmers Mfg. Co.

JOINT MEETINGS of utility and manufacturer engineers establish effective schedules and procedures for installation, operation and inspection of steam turbine-generator units.
Photo courtesy Texas Electric Service Company

Utility-manufacturer planning conferences establish installation, operation and inspection procedures . . . assure high reliability and efficiency levels for modern steam turbine-generator units.

INSTALLING STEAM turbine-generator units, like operating and inspecting them, is a precise assignment that requires not only skilled engineering personnel but also detailed, well-planned work procedures. The close cooperation between turbine producers and purchasers in furnishing these elements (skilled manpower and effective work programs) is the best assurance that a properly designed machine will perform efficiently and reliably. Turbine manufacturers have always provided supervisory engineers for the field assembly of their units, and in recent years have extended their responsibilities to include training unit operators and assisting in major maintenance-inspections.

These field services are of growing importance to utilities who realize that the increased internal efficiency of today's high-temperature, high-pressure units is due largely to closer control of manufacturing, installation and operation. Because these machines incorporate numerous construction features for controlling temperature changes and preserving proper alignment, the recommendations of the equipment designer and builder are very important in determining proper installation, operation and inspection procedures. To establish these procedures and arrange for them to be carried out, detailed planning conferences are frequently held at the plant site several weeks in advance of each scheduled job assignment. Such conferences contributed immeasurably to the record high average availability achieved last year by power companies in the United States.

Planning conferences outline installation procedures

Modern large capacity steam turbine-generator units are as precisely built as fine watches and operate at extremely high temperature and pressure levels for most efficient service. Because the successful performance of such equipment depends on accurate alignment and assembly of components during field erection, installation procedures must be well organized and carried out under the supervision of highly skilled carefully trained installation engineers. This care results in the unit being installed correctly, quickly and efficiently.

In pre-installation conferences district representatives plus turbine design engineers and service supervisory engineers meet with representatives of the power company and contractor to discuss all phases of the job; a service especially beneficial to customers and consulting firms that may be working with the turbine manufacturer for the first time.

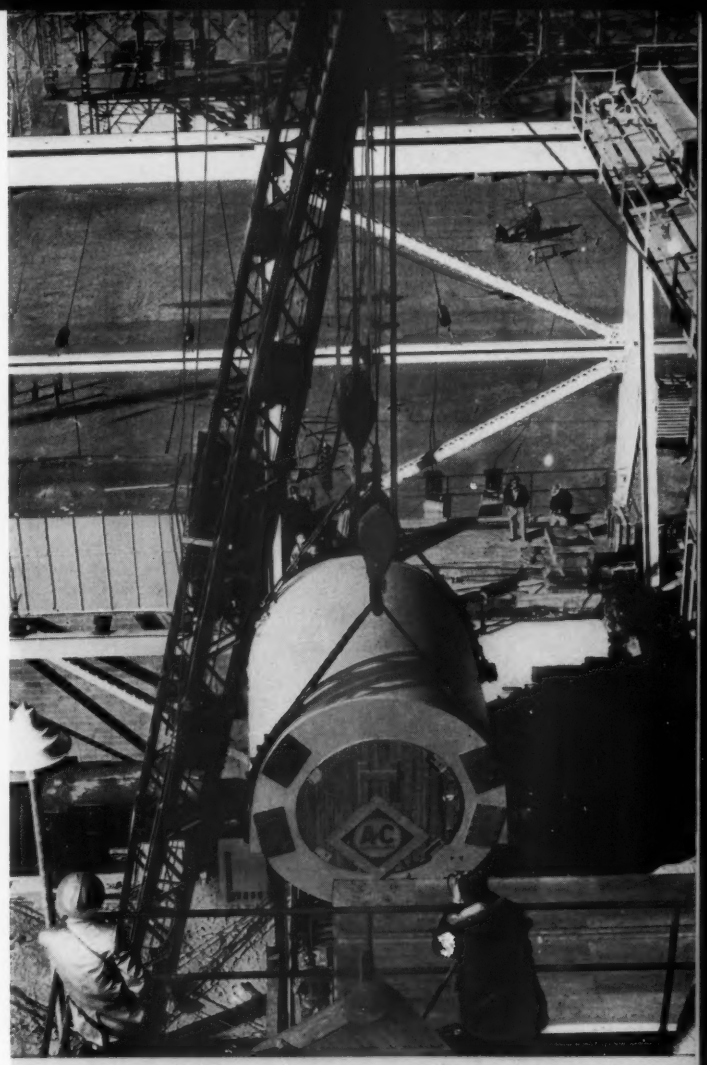
Electrical and mechanical characteristics of the unit are not only explained at the pre-installation conference but booklets containing a general description of the equipment — including weights, dimensions and recommended assembly procedures — are distributed. In addition, photographs, slides and blueprints are available to aid in under-

standing the construction of the turbine-generator unit so that everyone can visualize just what they will be working with and make their plans accordingly.

A prior knowledge of the heavier pieces to be handled during assembly, for instance, will enable the construction superintendent to determine the most efficient way of handling these large parts. Adequate quantities of compressed air, electricity, contractors' tools and other supplies can also be pre-determined at these meetings . . . all seemingly unimportant details but items that could result in costly delays in the erecting schedule. Besides the thousands of dollars per day lost in the field assembly, errors in planning could postpone the operating date of the unit and add further expense to the power company by forcing it to meet new load demands with less efficient equipment.

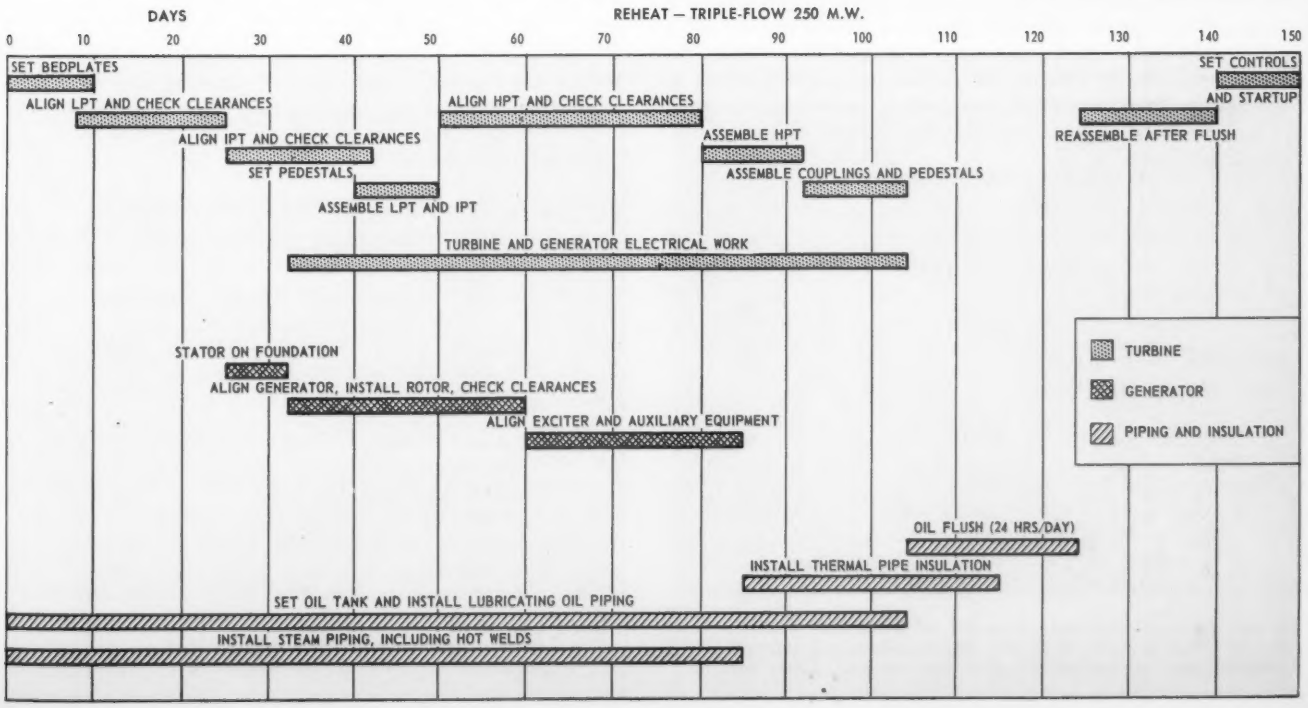
Responsibilities and duties of the installation superintendent, contractor's personnel and utility construction crews are also outlined at the pre-installation conference. This procedure eliminates future misunderstanding of where an individual's authority starts and stops, preventing conflicting situations from rising at the plant site and assuring that efforts of workmen will be used to the best advantage. The erector in charge is designated as the manufacturer's project manager and any questions concerning *existing equipment* or *equipment being installed* will be taken up with him. This unit responsibility on the jobsite assures the purchaser of quick and correct handling of all questions, even if they concern machinery not included in the present contract.

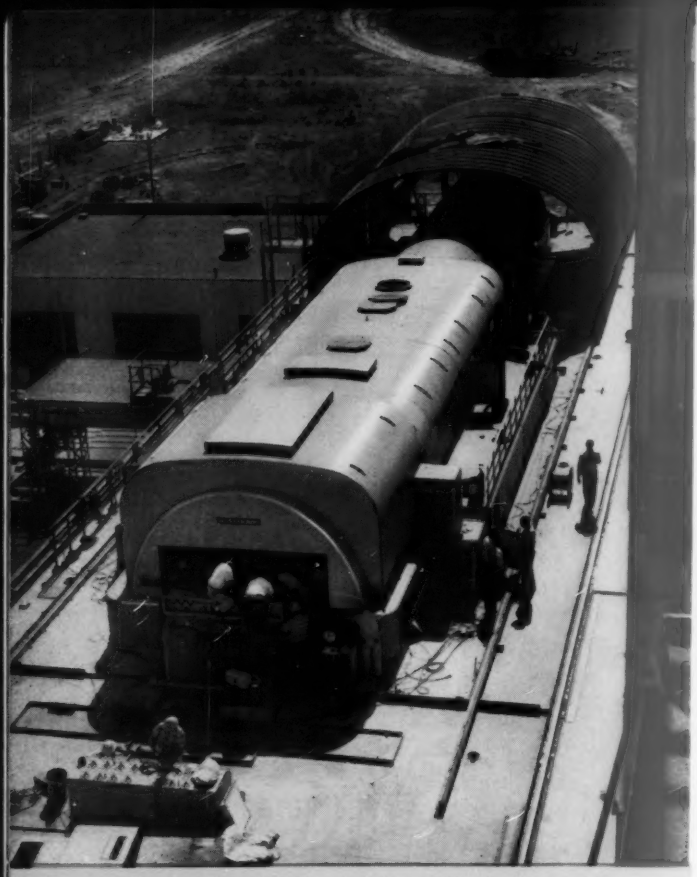
One of the most important topics discussed at the meeting is the estimated installation schedule. Shown in bar-chart form, the schedule serves as a guide for all operations



PROPER PLANNING enabled this heavy lift, 75-mw stator, to be made quickly and safely -- a major benefit utilities derive from pre-installation conferences. Crane capacity, manpower and material requirements are established to reduce erecting time and expense.
Photo courtesy El Paso Electric Company

MAJOR INSTALLATION PROCEDURES are indicated in bar chart form for tandem triple-flow unit. Graph of sequence of events, in days, enables installation superintendent to easily determine job progress and to allocate construction crews accordingly.





FINAL STEP in installation schedule is setting turbine controls. Months of careful work, including accurate assembly and alignment of components, pay off with smooth start-up. Later, appraisal group from the turbine manufacturer will visit plant to discuss operation.
Photo courtesy Houston Lighting and Power Company

from shipment to startup. It is valuable not only for the field erection of the machine, but also for establishing shipping sequences. These factors are taken into consideration when preparing the installation schedule so that shipments are timed to reach the job at the proper moment.

The chart also aids in determining the approximate time required for each phase of installation, enabling work crews to be efficiently employed at all times. In addition, it permits the installation superintendent to visually keep track of erection progress and quickly determine the effects of any changes in the assembly procedure.

Unit appraisal service valuable

Because proper installation of the unit is so important to its continued good performance, appraisal groups from the turbine manufacturer generally visit the jobsite 1 — 2 months after initial start-up. Consisting of representatives from the manufacturer's sales, design and field service engineering sections, the team meets with utility personnel from the management, power production, maintenance and construction departments. Together, they discuss and appraise the new machine in light of initial operating data.

A most important part of the appraisal meeting centers around the close visual inspection given the machine and plant. At this time any remaining work is noted and arrangements made for handling it. With the satisfactory completion of the job, a thorough evaluation is made . . . with the goal of determining what, if any, modifications may be desirable in the manufacturing, installation or initial operation phases of future units.

Operators' training is emphasized

Recognizing that continued good performance of a steam turbine-generator unit depends directly upon the abilities of operating personnel, power companies and turbine manufacturers are also placing increasing emphasis on proper training of operators. Modern reheat units each represent a multi-million dollar investment that must be operated at peak efficiency to show a reasonable return. This means that even before a new machine is started for the first time, detailed operating instructions must be established, and the operating personnel must become thoroughly familiar with the controls and equipment provided on the new unit.

Turbine test and startup engineers visit the plant several weeks before the installation is completed for the purpose of conducting training classes for the operators.

These pre-operating conferences acquaint utility people with their new unit and enable them to learn recommended operating procedures so that the machine will give maximum performance and reliability from its very first day of service. As in pre-installation conferences, visual aids speed understanding of the unit's construction and operation. Instructors use slides and photographs as well as the unit's own particular instruction book to illustrate their discussion. Training classes include a description of the parts and complete explanation of their operation. Special attention is given such items as primary and reheat steam valves and their control as well as the lubricating oil system, governing system, control and safety devices, gland steam sealing system and supervisory instruments.

Recommended starting and loading rates are also discussed in detail. These latter subjects are especially important for large capacity, high temperature units. Precise control of temperature gradients in these machines is mandatory if operating clearances and alignment are to be maintained. Because the overall length of a large turbine can increase as much as 1½″ between cold and hot operating conditions, understanding instructions and careful adherence to operating procedures is necessary for top performance and reliability.

Pre-inspection conferences reduce downtime

At no time is proper planning more necessary than when a unit is scheduled for a general maintenance-inspection. Careful coordination is especially necessary for the unit's first major planned outage, usually at completion of first year's operation. Then an advanced planning conference between personnel from the power company and the turbine manufacturer is essential in order to keep downtime at a minimum and also accomplish the objectives of the inspection.

Because many of the conditions that affect turbine performance occur gradually over a period of time, advance warning is often given by operating reports and recorded data. Proper analysis of these records at the meeting enables corrective measures to be taken before serious diffi-

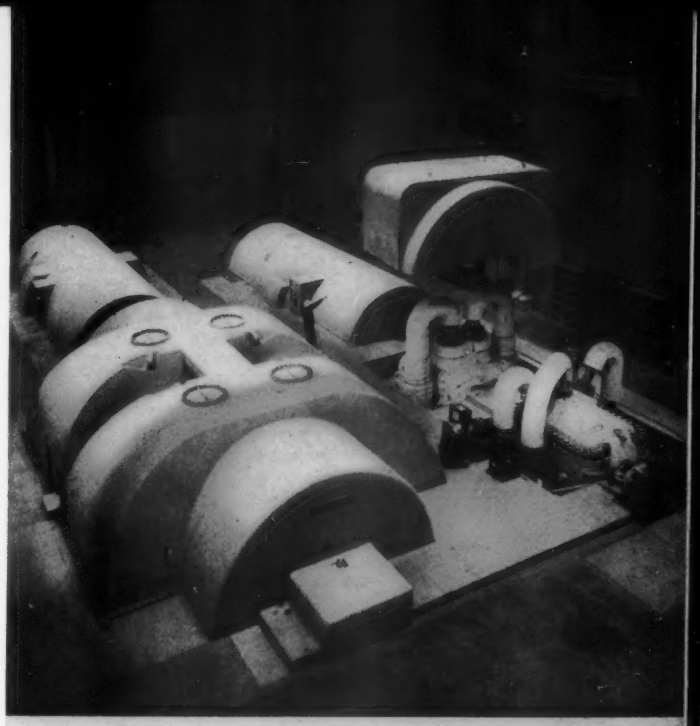
culty arises. Also, by studying the past operating record of similar machines, the turbine and generator service engineers can get a good idea of how the unit has been functioning. Their experience with machines of similar design helps them to guide the power company maintenance crews. Components subject to wear can be scheduled for close investigation and approximate manpower requirement established. If replacement parts are required they can be on hand before the unit comes down so that work can begin immediately.

Utilities find pre-inspection meetings especially beneficial for several reasons. First, discussion of the step-by-step inspection procedure and estimated work to be done enables the power company to schedule the outage so that standby generating equipment can be conveniently placed in service. Also, an overall work schedule can be prepared similar to the bar-chart used for installation procedures. The chart simplifies the job of deciding shift hours to be worked, personnel allocation (from both the turbine manufacturer and the utility), material requisitioning and establishing delivery and startup dates.

Although the schedule is not a rigid time table, it does give all concerned enough idea of timing so that the power company's other operations can be scheduled to fit in with this particular shutdown. The bar-chart is also useful to the turbine builder for checking actual times for each operation against estimated time, so that future estimates can be made more accurately.

At the pre-inspection meeting, service representatives, who will be present during the overhaul, go over each phase of the inspection with the power company's maintenance superintendent. In addition to other particulars of the job, they make certain that adequate lay-down space and crane capacity will be available so that after the unit is taken off the line, work can proceed as smoothly as possible.

Turbine manufacturers and utilities have learned that time spent in planning and preparations for installation, operation, or inspection of the unit, is not only desirable, but necessary for today's modern steam turbine-generators.



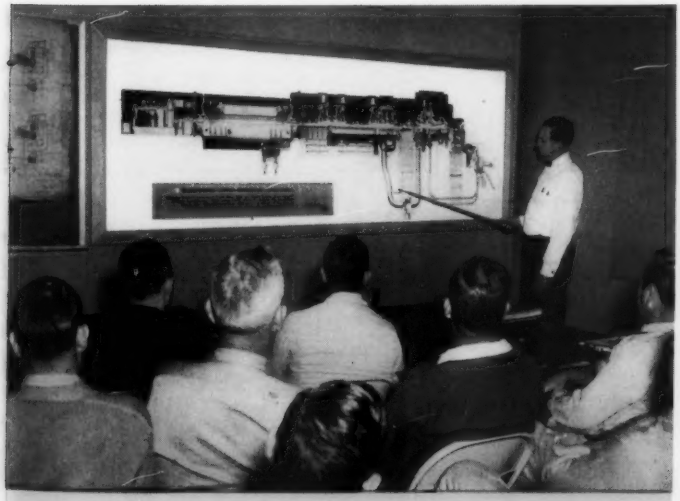
EVEN BEFORE completion of field assembly of units such as this 275-mw machine, start-up engineers are installing the necessary instruments to check the initial performance of the turbine.

Machines so powerful and intricate must be accurately aligned and assembled during installation, must be operated with care, and must be periodically inspected as part of an organized preventive maintenance program.

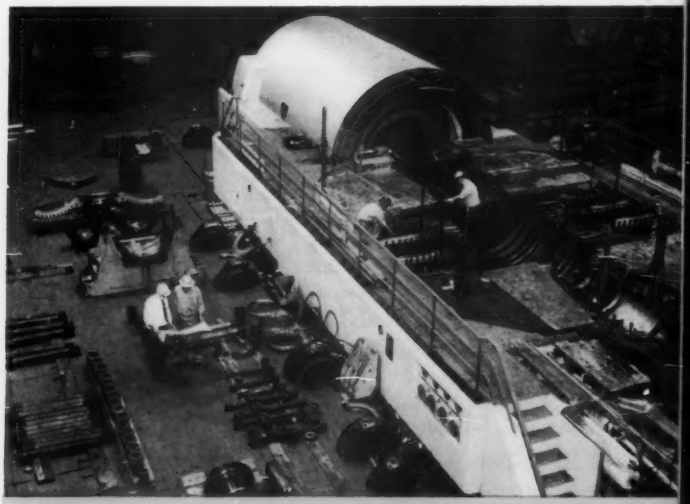
Through advanced planning conferences, these considerations are discussed and procedures established for their discharge. The result is improved unit performance due to reliable operation at high efficiency.

REFERENCES

1. "Factors Influencing the Reliability of Large Steam Turbine-Generator Units," C. D. Wilson, presented before Twenty-Second Annual Meeting of American Power Conference, March, 1960.
2. "So — You're Going To Overhaul Your Turbine-Generator," N. S. Jones, series of articles, *Power Engineering*, April, 1955 — August, 1956.



PRIOR TO START-UP of new machines, training classes for utility operating personnel are conducted by representatives of turbine builder. Control of unit and detailed operating instructions are covered.



CAREFUL PLANNING for first major maintenance-inspection reduced downtime and permitted service work to be completed during off-peak load period. Laydown space, crane facilities and crew were available.

CT's Oversaturated?

by A. H. KNABLE
Switchgear Department
Allis-Chalmers Mfg. Co.

Will current transformer saturation cause relaying problems on your system? Here's how to check.

SATURATION OF A CT can be caused by adding more burden to its secondary than it was designed for. This burden can be the result of placing a number of meters or relays in series in the CT secondary circuit. Another cause of over-saturation is long leads between CT and meters or relays.

Occasionally there are systems having high fault currents and CT's with high ohmic burdens. This combination can cause high CT saturation which flattens out the relay characteristic curves so that a greater line current is required to trip the relay in a given time as shown in Figure 1.

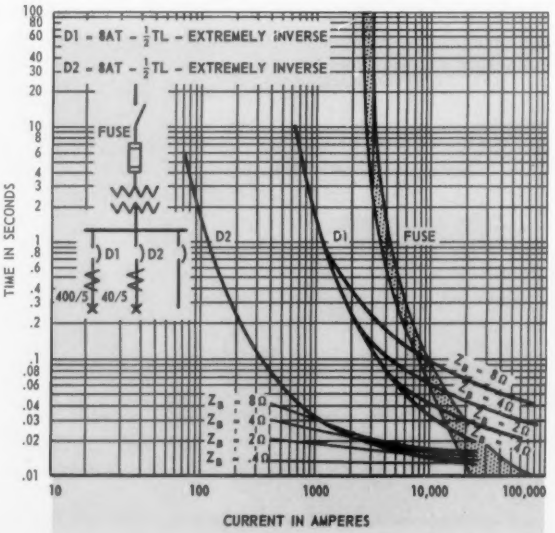
When relays with steep slope characteristics are used in conjunction with other relays having shallow slope characteristics, or fuses, the flattening out effect of the relay characteristics can result in tripping of breakers or blowing of fuses out of sequence. The graphs shown in Figure 2 not only indicate when CT saturation is a problem but also how to correct the relay curves for the error introduced by saturation when it is present. Since these curves are based on a zero power factor load, any burden greater than 0.4 PF will introduce less error than shown by curves.

The example shown in Figure 1 illustrates the use of Figure 2. The relay curve D1 ahead of the fuse is plotted to permit a breaker time of 0.1 second plus 10 percent tolerance in breaker characteristics plus 10 percent tolerance in fuse curves. The resulting curve plotted with the relay manufacturer's information is shown as the solid curve D1. The effect of saturation and burden is determined from Figure 2 and results in a family of broken lined D1 curves as shown in Figure 1.

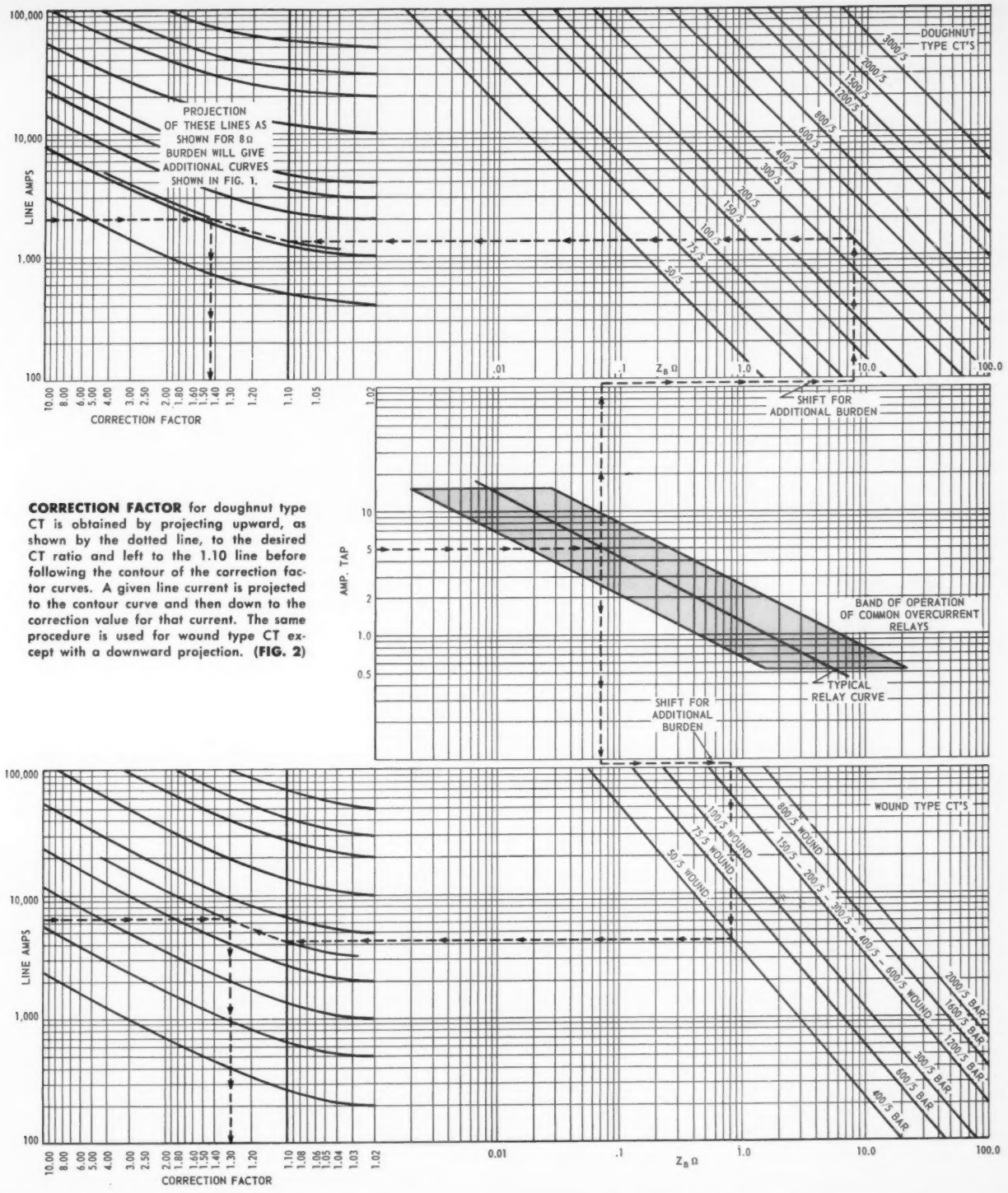
When CT burden is high, saturation shifts the relay curve up into the fuse curve and results in improper coordination. The burden in ohms of the instruments in series with the relay can be accounted for by shifting the vertical projection in Figure 2 to the right by an amount equal to the series impedance of the additional instruments, such as meters and other relays. The burden in volt amps is available in the instrument manufacturer's published literature. The burden in ohms is also generally listed. If only VA is listed the ohmic value can be determined from the equation $Z = \frac{(VA)}{A^2}$

An inspection of curve D2 shows that the common expression "high fault capacity system with low CT ratios results in false tripping" is not necessarily a dangerous combination. A very high burden is also necessary. A relay having a flat characteristic is not greatly affected by CT saturation since a large horizontal projection to the right will shift the curve upward only slightly. This shift can be seen from the D2 curve having an 8 ohm burden.

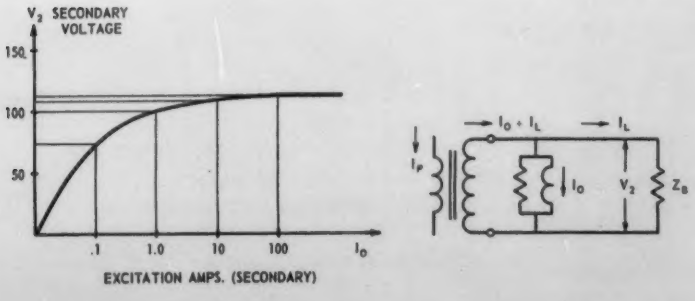
Where there are no high burdens there are no saturation problems even when small CT ratios are involved. When there is any doubt, the curves of Figure 2 can be used to quickly check CT burden.



CHANGE in relay characteristics with change in burden is shown for 400/5 and 40/5 CT's. (FIGURE 1)

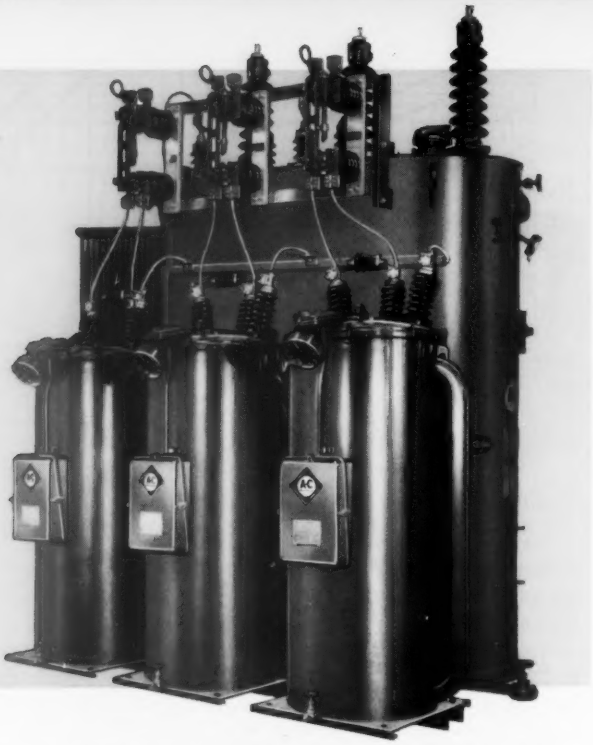


CORRECTION FACTOR for doughnut type CT is obtained by projecting upward, as shown by the dotted line, to the desired CT ratio and left to the 1.10 line before following the contour of the correction factor curves. A given line current is projected to the contour curve and then down to the correction value for that current. The same procedure is used for wound type CT except with a downward projection. **(FIG. 2)**



IN GRAPHIC APPROACH, V_2 is used to link I_0 with I_L where $I_0 + I_L = I_P$. The V_2 is established as $I_L Z_B$. V_2 is used to establish I_0 from the CT saturation curve. The $(I_0 + I_L)$ or I_P is then determined as a certain percent in excess of ideal for the various multiples calculated; that is $\left(\frac{I_0 + I_L}{I_L}\right)$ represents error present. **(FIGURE 3)**

REGULATORS AND TRANSFORMERS *Combined* FOR SUBSTATIONS



THREE REGULATORS mounted as an integral part of transformer provide individual phase regulation and simplify installation.

by T. J. SILLERS
Regulator Department
Allis-Chalmers Mfg. Co.

Joining single-phase regulators and standard three-phase transformer in one compact unit solves substation space problems.

MORE ECONOMICAL USE of substation space, simplified maintenance, lower installation costs, and greater flexibility are obtained with new regulator transformer combination.

Basically, this unit consists of a standard three-phase transformer and three single-phase regulators connected to the low voltage side and mounted directly on the transformer tank. By-pass switches, mounted adjacent to the low voltage bushings of the transformer, are used to electrically disconnect the regulators.

The unit can be shipped with the regulators mounted on the transformer and all connections between them made at the factory. With this arrangement, it is only necessary to make connections to the high voltage side of the transformer and load side of the regulators for installation.

However, the unit can also be shipped as two items, the transformer and bypass switches as one item and the regulators as the other.

In addition to saving installation time, other savings are realized. Less overhead line structure is required because switches and connections between the transformer and the regulators are an integral part of the unit. It is not necessary to pour a separate concrete pad in one area of the substation for the transformer and another for the regulators. Space requirements are approximately the same as those of an equivalent sized load tap changing transformer.

Individual phase regulation is available

By incorporating three single-phase regulators with a standard three-phase transformer, all the benefits of individual phase regulation are available. In substations having outgoing feeders handling single-phase loads on all three phases, each phase will be regulated individually according to its own loading.

The regulators may be bypassed for maintenance or service because they are connected to the transformer by bypass switches. Service to the loads supplied does not have to be interrupted to maintain the regulators, making possible convenient, scheduled maintenance programs.

To service a particular regulator, the switch is put in the open position to carry the load, thereby bypassing the complete regulator. The regulator is then unbolted from the transformer and moved to a convenient area for untanking. Inasmuch as the bypass switch is external, the operator has visual proof that the regulator is on or off the line, thus insuring operating safety.

If it should happen that one of the regulators needs to be taken to a shop for repair, another regulator from stock could be put in its place. However, the substation could continue to operate, with one or more phases unregulated while repairs or replacements were being made.

Since the regulator can be taken from the transformer without disrupting service, it is not necessary to bring in

a mobile substation during maintenance or service operations.

Flexibility of unit is apparent

All of the benefits of the single-phase regulator are incorporated in the new unit. The ability of the individual regulators to carry loads up to 160 percent of their nameplate ratings by decreasing the range of regulation adds to the flexibility in ratings. Standard ratings would provide plus or minus 10 percent regulation in 32-⅝ percent steps for substations up to 7500 kva in the 12,000 to 13,800 volt range and up to 5000 kva at 2500, 4330, 5000 and 8660 volts. Where plus or minus 10 percent regulation is not required, utilization of the Vari-Amp feature will make possible the use of lower rated regulators, reducing cost and size. For example, a 5000 kva load at 13,200 volts would use three 167 kva, 7620 volt regulators and provide plus or minus 10 percent regulation. If plus or minus 5 percent regulation is all that is required, three 114.3 kva regulators can be used to carry the 5000 kva load.

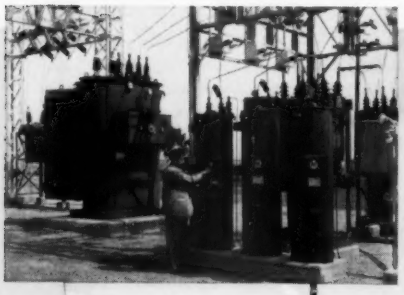
It is also possible to utilize this feature and still realize a 10 percent boost from the regulator. In the above example we could choose a 5000 kva transformer with a secondary voltage of 13,800 or 5 percent above the 13,200 volts. Then, by setting the regulators for plus 5, minus 10 percent, the unit will maintain 13,200 volts with a plus 10, minus 5 percent regulation. With the load such that the output voltage of the transformer is 13,800, the regulators will buck the voltage down 5 percent to 13,200. From its minus 5 percent position the regulators can raise the output voltage 10 percent and lower it 5 percent. Over the 10 percent boost range, the regulator can carry 160 percent current so it is again possible to use the 114.3 kva regulators instead of the 167 kva units in the previous example.

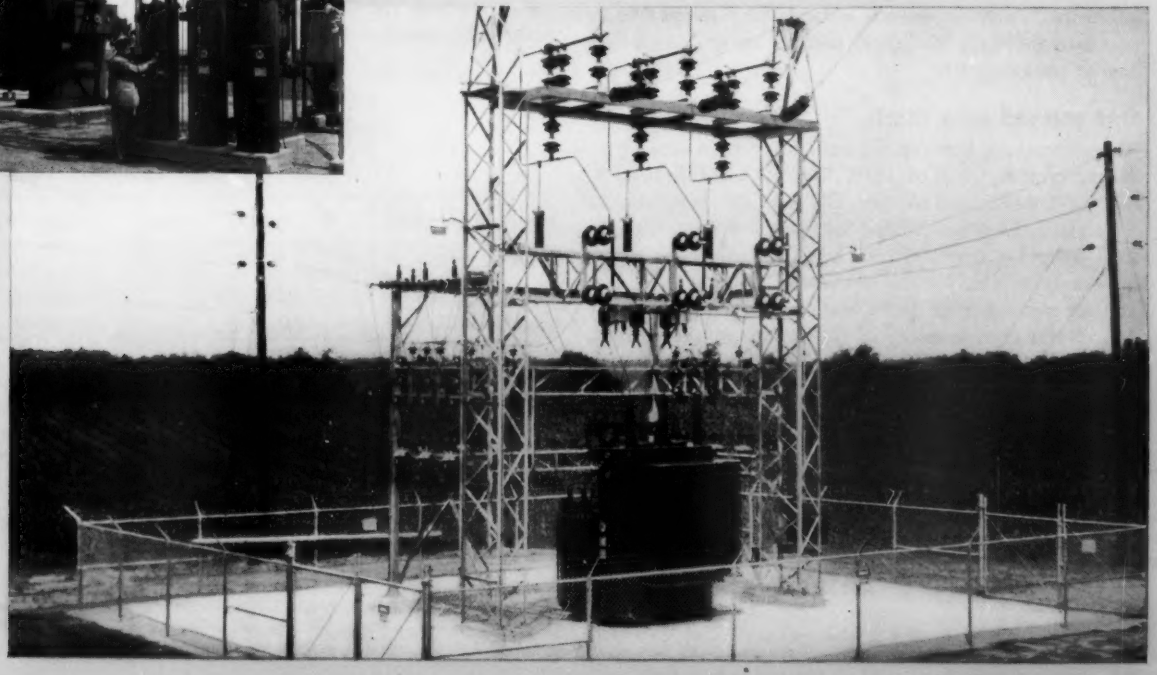
The new arrangement, combining three regulators with a transformer, offers all of the features and advantages of separately installed transformers and regulators in one compact, space saving unit.

COMPARISON OF ALTERNATIVE ARRANGEMENTS

	Combined Regulator and Transformer	Conventional Three Phase LTC	Separate Regulators and Transformers
Individual phase regulation	Yes	No	Yes
Tap changer can be maintained without interrupting service	Yes*	No	Yes*
Built in potential source for controls	Yes	No	Yes
Only one foundation pad	Yes	Yes	No
Can be shipped as separate items to areas where shipping size is critical	Yes	No	Yes
Vari-Amp a standard feature	Yes	No	Yes
Unit can be located directly below high voltage structure with low voltage structure connected to high voltage structure (smaller more compact structure required)	Yes	Yes	No
Transformer and regulators can be used at separate locations in future if desired	Yes	No	Yes

*Entire regulator can be removed from service by use of externally mounted bypass switches. The operator has visual proof that the unit is bypassed from the line and safe to work on.





NEW ARRANGEMENT requires less space and less overhead structure. It performs same function as conventional arrangement (left) but with lower installation cost.

OVERLOADING TRANSFORMERS

by W. C. SEALEY
Chief Engineer
Transformer and Regulator Departments
Allis-Chalmers Mfg. Co.

"How much can I overload my transformer in an emergency?" This question can be quickly answered using a simple set of curves and data.

THE AMERICAN STANDARDS Association (ASA) "Guides for Overloading Transformers" provide general loading cycle data for a constant load following a short time peak load with cycles repeating every 24 hours. There are two simple methods of handling more complex load cycles, one using charts and the other using curves.

A 10,000-kva OA transformer operating in a 30C ambient and having the daily load curve given in Figure 1 can be used to show the two methods of solving overload problems. In both methods a rectangular stepped curve is drawn about the load curve and is used in determining loss of insulation life.

One method uses charts

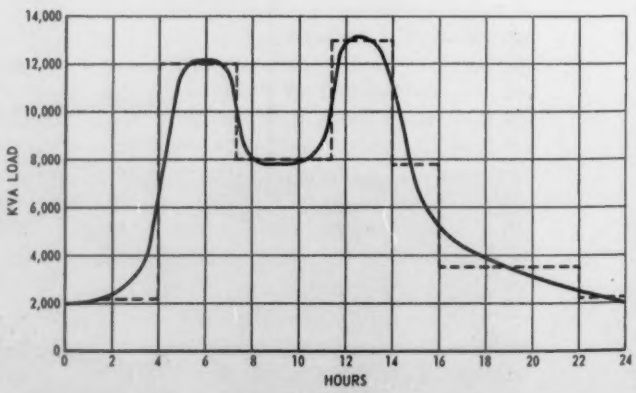
Three charts are given in Figure 2 for various cooling arrangements; A_1 for FOA, FOW, OA/FOA or OA/FA/FA, A_2 for OA/FA and A_3 for OA or OW transformers. Columns 1, 2 and 3 of Table I are filled in starting with the load following the minimum load. An initial oil rise is arbitrarily selected for the first line in Column 4. A convenient starting point is the rise for the continuous time (∞) value corresponding to the percent minimum load. Referring to chart A_3 for the OA transformer in this case, the first initial oil rise, Column 4, line a, of Table I, is selected as 18 degrees which corresponds to the infinite time oil rise for 22 percent load on the right side of the chart. Placing a straight edge between the initial rise at 0 time on the chart and the percent load at ∞ time, the final oil rise for Column 5 is read at a point corresponding to the duration hours of Column 2.

The initial oil rise for line b is the same as the final oil rise of 43 just recorded. Proceeding as before the straight edge is placed between 43 degrees at 0 time and 80 percent load ∞ time as shown on the chart. The oil rise for 4.2 hours is 37 C.

This procedure is continued, repeating the cycle until the final oil rise for the same place on the cycle is the same on successive calculations. The values for lines a and g in Column 5 are both 43 C.

Using only the last complete cycle (lines b to g), values of Cu gradient are determined from Figure 3 and Column 6 is filled in. Column 7 is obtained by adding the values from Columns 5 and 6. Column 8 is obtained by adding 30°C, the ambient temperature to the values of Column 7. The percent loss of life per hour values in Column 9 are taken from Figure 4 and correspond to the values in Column 8. Values below 95 C may be disregarded in calculating loss of life. The percent loss of life in Column 10 is the product of Columns 2 and 9.

The total loss of life per cycle is the sum of the figures in Column 10. The life of the transformer in this case, will be equal to $\frac{100}{0.091}$ or 1100 days of such loading. Whether such loading is satisfactory depends on how often this and other loads will be repeated and what loss of life is permissible for the application. On a continuing life time basis the loading is probably too heavy. However for emergency loading, it is too light.



RECTANGULAR STEPPED WAVE is drawn about load cycle curve to obtain values in Tables I and II used in solving load problems. **(FIGURE 1)**

TABLE I

Column No.	1	2	3	4	5	6	7	8	9	10
Line	Kva Load	Duration — Hrs	% Load	Initial Oil Rise	Final Oil Rise	Cu Gradient	Cu Rise	Cu Temp	% Loss of Life/Hr	% Loss of Life
a	12000	3.3	120	18	43					
b	8000	4.2	80	43	37	14	51	81	—	—
c	13000	2.5	130	37	51	31	82	112	.029	.073
d	7800	2.0	78	51	42	14	56	86	—	
e	3500	6.0	35	42	23	4	27	57	—	
f	2200	6.0	22	23	19	2	21	51	—	
g		3.3	120	19	43	27	70	100	.0055	.018
						Total				.091/cycle

30°C Ambient
T = 3

TABLE II

Column No.	1	2	3	4	5	6	7	8	9	10	11	12
Line	Kva Load	Duration — Hrs	% Load	Initial Oil Rise	Initial Curve Time — Hrs	Final Curvetime — Hrs	Final Oil Rise	Cu Gradient	Cu Rise	Cu Temp	% Loss of Life/Hr	% Loss of Life
a	12000	3.3	120	18	.65	3.95	43					
b	8000	4.2	80	43	7.0	11.2	37	14	51	81	—	
c	13000	2.5	130	37	2.1	4.6	51	31	82	112	.029	.073
d	7800	2.0	78	51	5	7	42	14	56	86	—	
e	3500	6.0	35	42	4.5	10.5	33	4	27	57	—	
f	2200	6.0	22	23	8	14	19	2	21	51	—	
g	12000	3.3	120	19	.7	4.0	43	27	70	100	.0055	.018
									Total			.091/cycle

30°C Ambient
T = 3

Second method uses curves

Three curves are shown for various cooling arrangements in Figure 5, B_1 for FOA, FOW, OA/FOA/FOA or OA/FA/FA, B_2 for OA/FA and B_3 for OA or OW transformers. The information in Table II is filled in starting with Columns 1, 2 and 3. The first initial oil rise in Column 4 is selected as 18 C corresponding to the infinite time oil rise for 22 percent load on the right side of the curves B_3 in Figure 5.

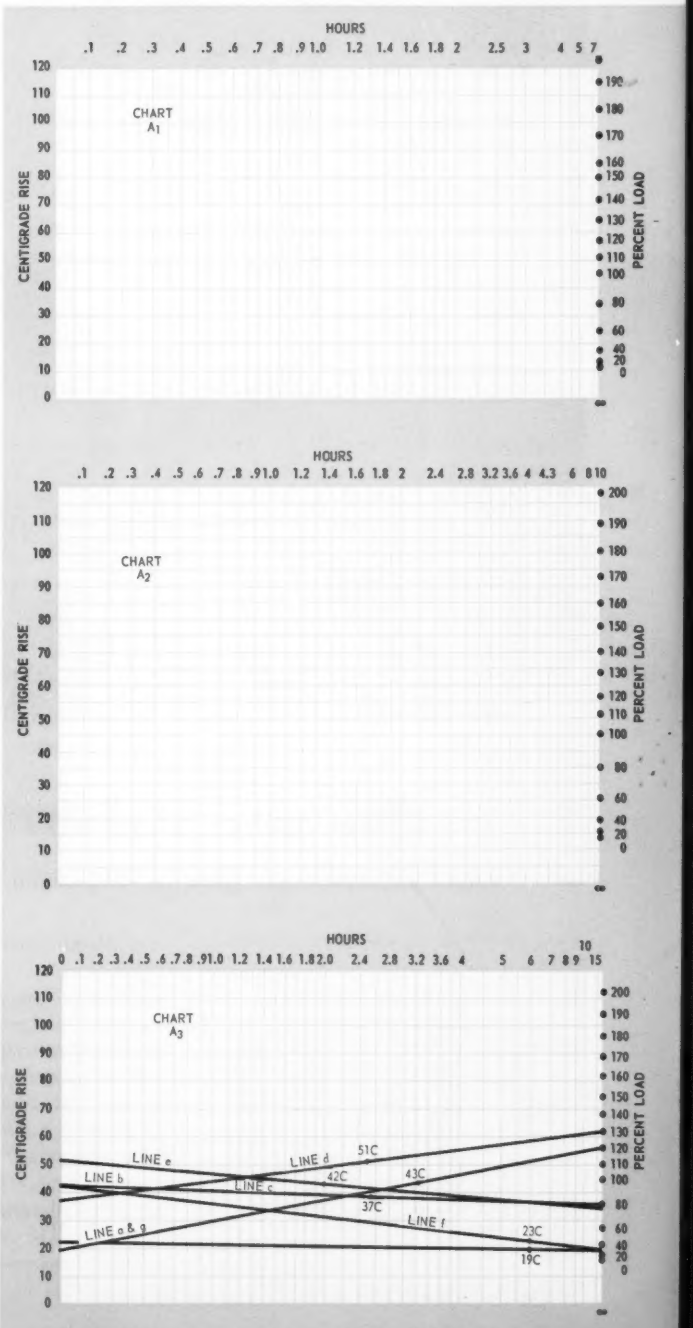
The initial curve time value for Column 5, line a, corresponds to 18 C rise on the 120 percent load curves. The final curve time value is the sum of the values on line a, Columns 2 and 5 or 3.95 hours. The final oil rise in Column 7, line a, is the C rise for 3.95 hours on the 120 percent load curve or 43 C rise. Note that there are two load curves for each load, a curve of increasing temperature and a curve of decreasing temperature. The initial oil rise automatically determines which curve is to be used.

The initial oil rise of 43 C for Column 4, line b, is the same as the final oil rise from Column 7, line a. The initial curve time in Column 5, line b, is the time corresponding to 43 C rise on the 80 percent load curve at 7 hours. The final curve is equal to 4.2 plus 7 or 11.2 hours. The final rise for Column 7, line b, 37 C is the value on the 80 percent curve corresponding to 11.2 hours.

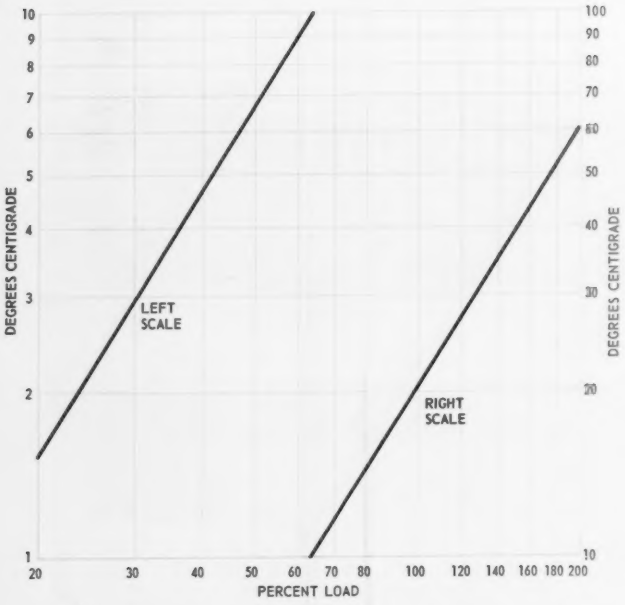
This procedure is continued, repeating the cycle until the final oil rise for the same place on the cycle is the same on successive calculations. In Column 7 on lines a and g, the same value (43 degrees) is obtained.

Using only the last complete cycle (lines b to g), values of copper gradient are determined from Figure 3 corresponding to the percent load in Column 3 and placed in Column 8. The values of Column 9, Cu rise, are the sum of the values in Columns 7 and 8. The Cu temperatures in Column 10 are determined by adding the ambient temperature 30 C to the values in Column 9. The percent loss of life per hour values in Column 11 are determined from Figure 4 corresponding to the copper temperatures of Column 10. Values below 95 C may be disregarded in calculating loss of life.

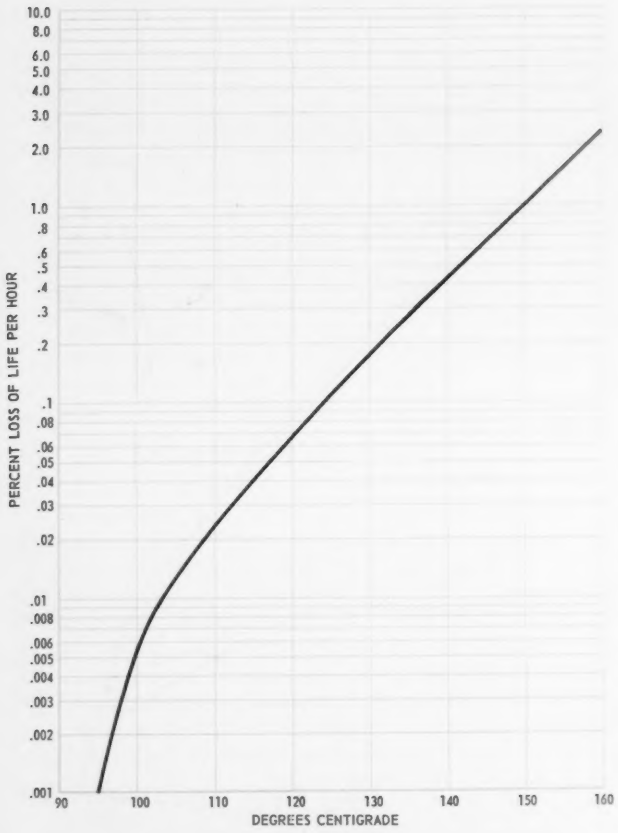
The percent loss of life (Column 12) is the product of Columns 2 and 11. The total loss of life per cycle is the sum of the figures in Column 12. It will be noted



CHARTS A_1, A_2, and A_3 are used for the first method. The lines on Chart A_3 show how data for Table I is obtained in example. **(FIGURE 2)**



CU GRADIENT in degrees Centigrade is read directly from curves, listed in Table I and used to obtain the Cu rise. **(FIGURE 3)**

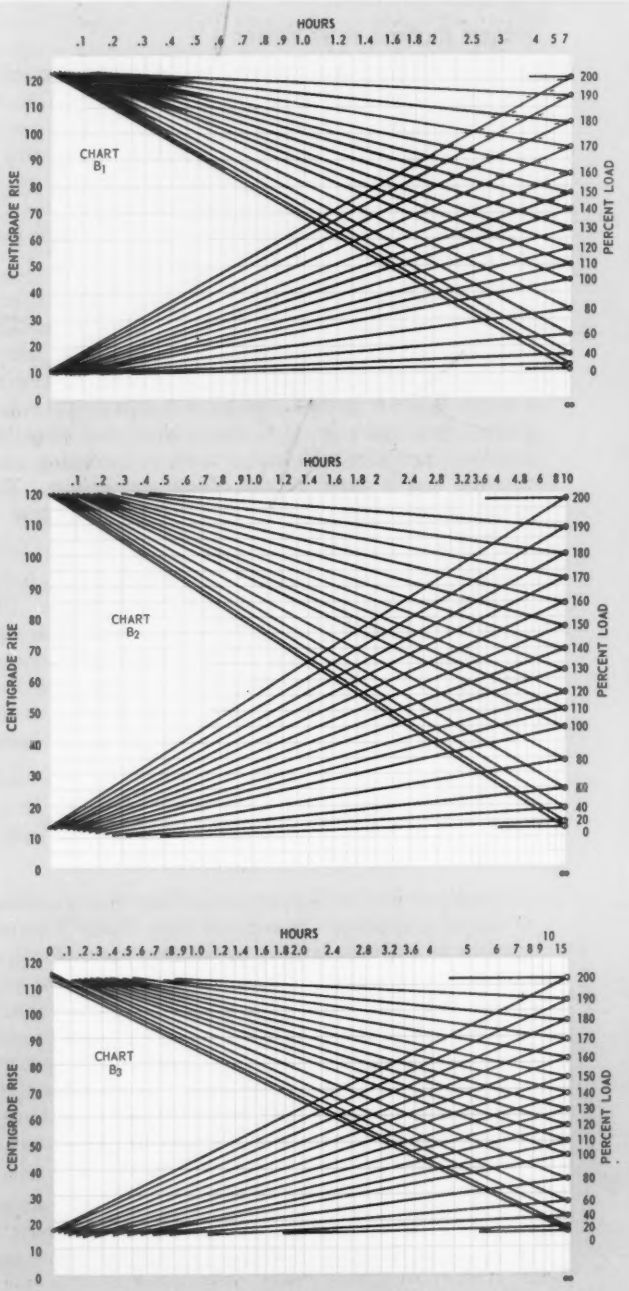


CU TEMPERATURE in degrees Centigrade is key to loss of life. If Cu temperature is over 95 C, loss of life becomes a factor. **(FIG. 4)**

that Charts A and Curves B produce identical results and the choice between them is a matter of personal preference.

The basic method and loss of life data are taken from the ASA guides. This loss of life data is generally believed to be more conservative than necessary. However, the methods described apply equally well when a different loss of life curve is substituted for Figure 4.

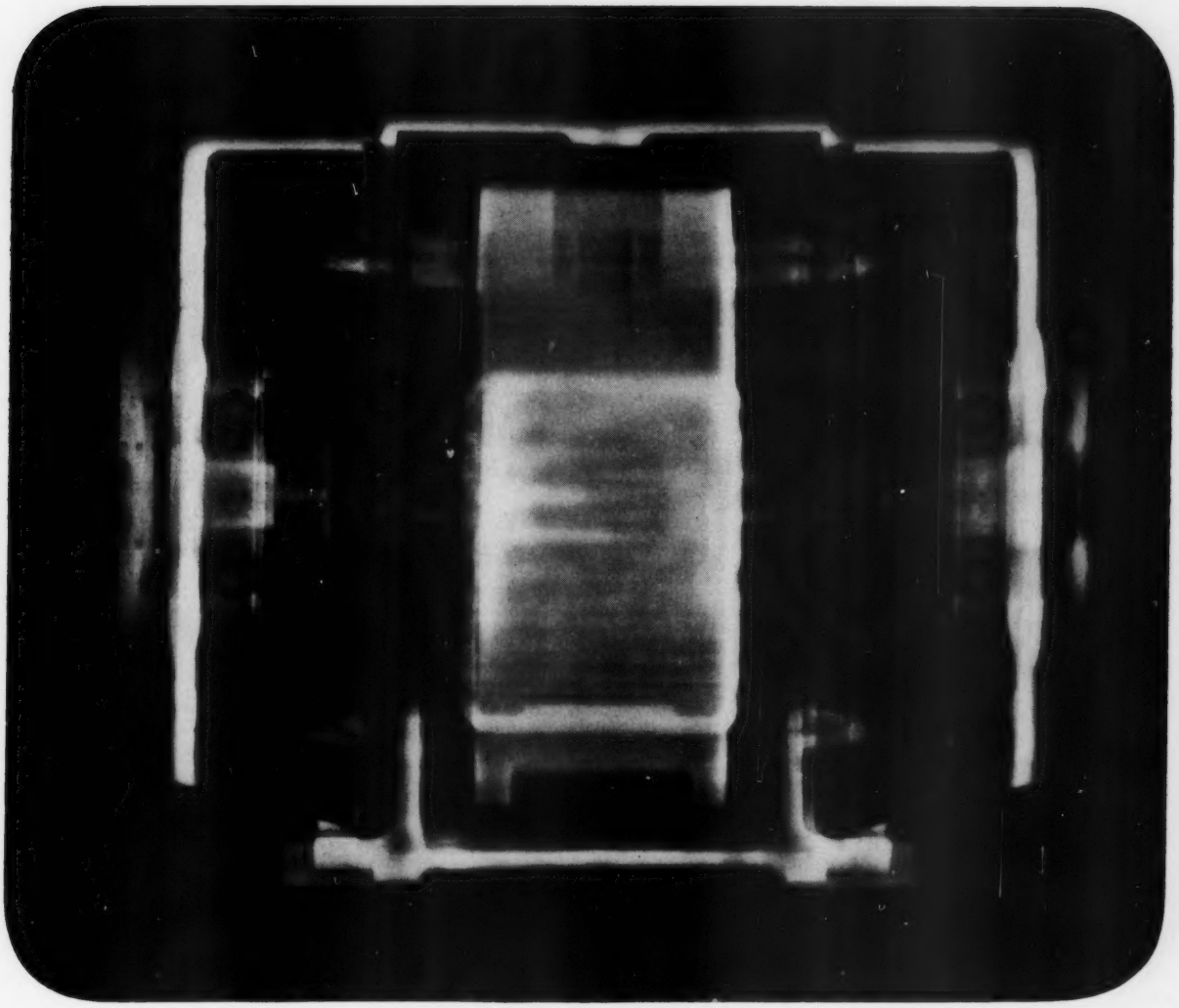
The purpose of these charts is to provide a rapid and convenient means of determining permissible overloading of transformers based on loss of life.



DATA for Table II is completed using Charts B_1, B_2 and B_3. Solution of example, showing second method, uses curves of Chart B_3. **(FIG. 5)**

ALLIS-CHALMERS

A-1337



Actual radiograph of a 5-hp open-type motor taken with a 24-million volt Allis-Chalmers Betatron.

X-ray view of motor health

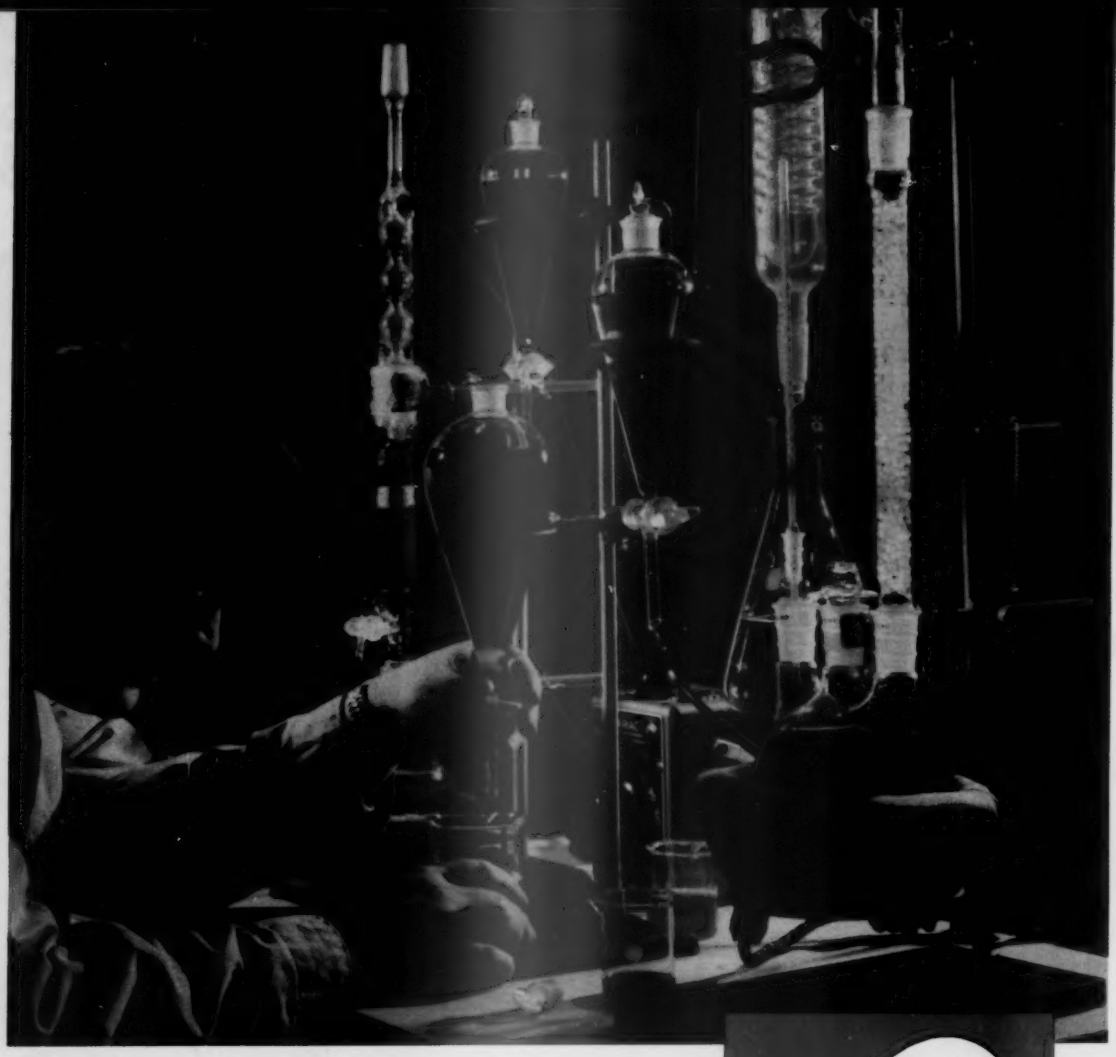
Invisible standards of perfection increase life expectancy of every Allis-Chalmers motor

The exceptionally long performance of A-C open motors proves the value of thinking *beyond* established standards of design . . . of taking "significant new achievement" as the ideal.

This ideal led to many refinements for A-C open motors: double-shielded bearings that keep dirt out and allow controlled migration of grease, permanently numbered lead spacer and leads for easy identification and connection, and heavy-duty cast iron frames that resist corrosion and keep rotating parts perfectly aligned.

For totally-enclosed, open-type and *Super-Seal* general purpose motors, and electrically or mechanically modified definite-purpose motors, choose the motor built to invisible standards of perfection. Choose A-C. Special application help available.

Call your nearby A-C representative. Or write **Allis-Chalmers,** *Industrial Equipment Division, Milwaukee 1, Wis.* *Super-Seal* is an Allis-Chalmers trademark.



Research in Ultra Purity

PHYSICAL AND CHEMICAL PROPERTIES of metals and chemical compounds of high purity are considerably different than the properties normally associated with standard purity.

Tungsten, for example, is normally thought of as a hard, brittle metal. However, in its pure state, tungsten is quite ductile. High purity iron has a tensile strength several times that of common iron. Slight impurities in a copper conductor can increase its ohmic resistivity fifty percent. Trace impurities, known as "poisons," can markedly reduce the activity of catalytic materials.

Laboratory quantities of metals with purities as high as 99.999+ percent are now possible for some of the more common metals. Production of metals and materials of high purity have required the development of new techniques and the renovation of older techniques in metallurgy and chemistry. Techniques involving the use of ion exchange resins, liquid-liquid extractions, crystallization, zone refining, sublimation and distillation have all been used to increase the relative purity of chemical compounds.

In the process shown, liquid-liquid extraction and distillation are used to separate metal chelate compounds. Other processes used in conjunction with this work are the sublimation and distillation of mixtures of metal chelates to effect a separation of the metals. Spectrographically pure products have been obtained by this method.

The immediate objective of research in this area of pure metals and compounds is to improve methods of preparing them and to explore the remarkable properties of these experimental products.

These newly derived characteristics may offer research scientists a new approach to probe the fundamental behavior of existing engineering materials.

PATRICK G. GRIMES
Research Division
Allis-Chalmers Mfg. Co.